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Forecasting in Military Affairs

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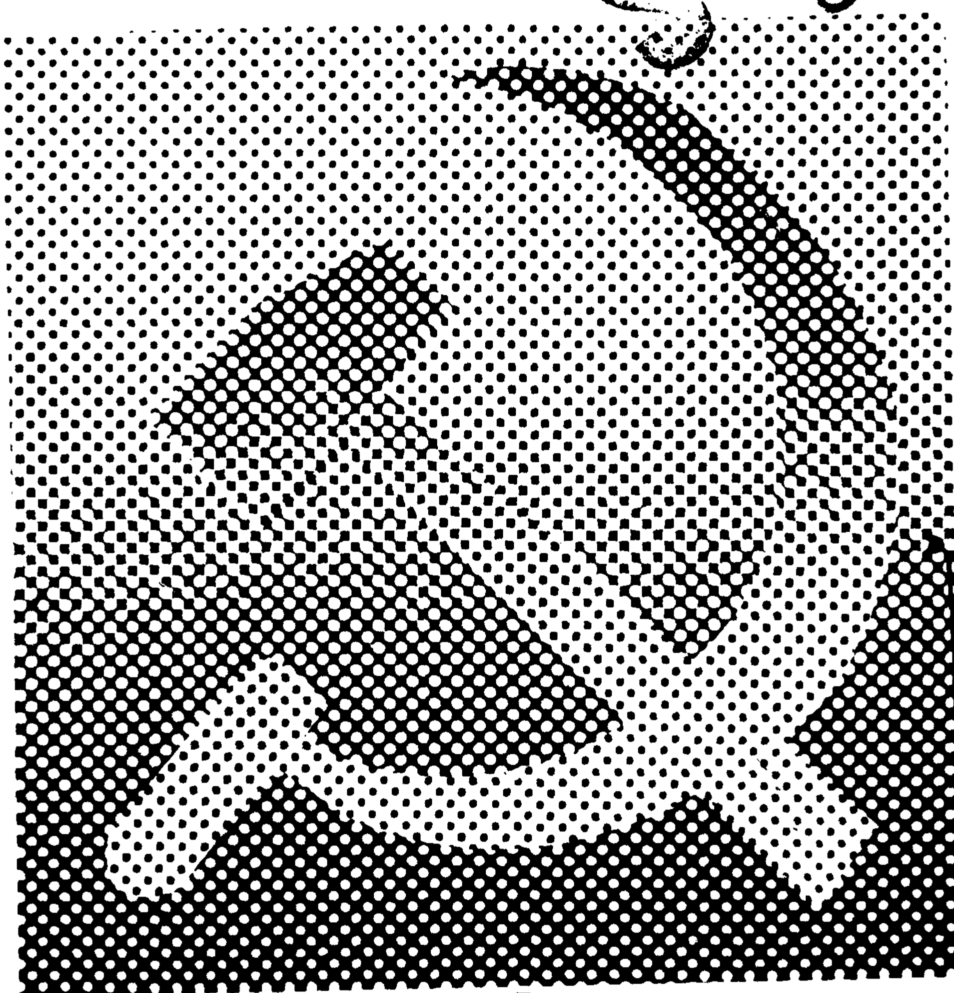
A Soviet View



SOVIET MILITARY THOUGHT

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Ю. В. ЧУЕВ, Ю. Б. МИХАЙЛОВ

ПРОГНОЗИРОВАНИЕ В ВОЕННОМ ДЕЛЕ

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Forecasting in Military Affairs

A Soviet View

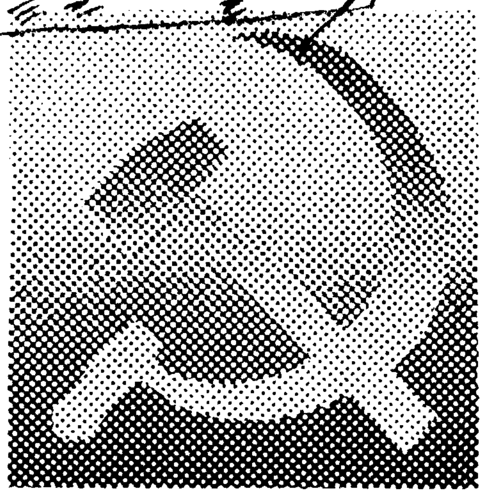

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Table of Contents

Part II: Forecasting in the Solution of Military Problems

American Editor's Comments

This English language edition of *Forecasting in Military Affairs* is the sixteenth volume in the "Soviet Military Thought" series, translated and published under the auspices of the United States Air Force. The Soviet edition was published in 1975 in 12,000 copies by the Voyennoye Izdatel'stvo Ministerstva Oborony SSSR [Military Publishing House of the Ministry of Defense of the USSR] and was described as being of interest to a wide audience of readers in the military, in industry, and in related educational institutions

This is the second book in the "Soviet Military Thought" series to be published under the requirements of the Universal Copyright Convention, to which the Soviets became signatories in 1973. Under these circumstances publication in the U.S. required that a copyright release be obtained. This was granted with the stipulation that the translation not include the "Conclusion" section of one and one-half pages at the end of the book. To that extent the English language version differs from the Russian original.

One of the stated purposes of the authors in writing this book was to make up for the lack of Soviet literature on the subject of forecasting as it applies specifically to military activities. The reader of the American edition may also find it interesting and a new experience in this respect, and he will welcome the wealth of examples illustrating various forecasting techniques.

The book provides a rather broad review on an international scale of recent thinking on the subject of scientific planning, forecasting, and decisionmaking as it relates to the military. The scientific approach to these matters is observed to be highly essential in an age in which scientific and technical development gives rise to rapid changes in weapons and techniques. The results of the use of nuclear weapons are likely to be such as to deny decisionmakers the luxury of a leisurely approach to their

task. Scientific forecasting is proposed as a means of ensuring the rapid production of soundly based information on which to make proper decisions in military affairs. It is not put forth as a substitute for the thinking of talented and experienced military experts but as a means for them to achieve their decisions in a more timely and scientific manner.

The authors employ a mathematical-statistical approach in arriving at their hypothetical forecasts, and, particularly because of the numerous examples of forecasting situations to which these techniques are applied, those involved or interested in the activity should be able to confirm their understanding of the methods of arrival at the various conclusions. Although some few items in the symbology may be new to the reader of English (some being devised for the one individual example they serve), good statistical techniques are employed and are quite familiar to students of statistics and forecasting.

Those who are new to Soviet writings may be fascinated, if not surprised, to see the teachings of Marxist-Leninist principles related to such endeavors as military forecasting. Those who have studied the Soviet Union will be familiar with the application of this philosophy to areas to which most readers in the West are unused to relating such doctrines.

The reader should note the bibliographic listing at the end of the book (arranged in Russian alphabetical order). The works listed there are all either simply cited in the text or used for source material, the referencing being done by placing the identifying number in square brackets at the appropriate point in the text, e.g., [76]. It should be pointed out that certain of these items are Russian translations of works that originally appeared in English. For the convenience of the reader the present U.S. translation of *Forecasting in Military Affairs* will include publication information for these items in the original English as well as for their Russian translations. Other items in the bibliography actually refer to original English language works but lack certain publication information that the reader of English customarily expects; this information has been added to that which appeared in the original.

In certain cases material identified as a quotation in the Soviet edition has been set in small print in the English translation. The reader should understand that this kind of distinction was not made in the original and that it implies no intended emphasis of that material either on the part of the Soviet authors or the American editor. The sole purpose for this was to facilitate reading.

The translation and publication of **Forecasting in Military Affairs** *does not constitute approval by any U.S. Government organization of the inferences, findings, and conclusions contained therein. Publication is solely for the exchange and stimulation of ideas.*

Abstract

This book analyzes existing and developing methods of forecasting (heuristic, mathematical, and composite) and examines their use in solving various military problems. It demonstrates the errors inherent in all the methods and how they affect the results of decisions that can be made and the final results of operations. The fields of application of particular methods are discussed and concrete examples are given.

The book is intended for a wide range of military readers and for workers in industry and related educational institutions.

Introduction

Forecasting has always been an important aspect of military affairs. The success of any operation or engagement is largely determined by how accurately the enemy's intentions and concrete plan of operations have been foreseen. Success in planning the development of the armed forces depends on the accuracy of forecasts of trends in the development of tactics, operational art, and strategy, as well as the quantitative and qualitative composition of the arms and military equipment of a probable enemy, economic potential, etc.

Nowadays there is a naturally greater need for scientific military forecasting. Contributing to this are the increasing rate of introduction of new weapons and military equipment, changes in the methods and forms of armed conflict, the rapid situation changes in modern combat, the increase in expenditures on arms and military equipment, etc.

"Under present-day conditions," writes General of the Army V. G. Kulikov, "the danger of miscalculations and errors in decisions has increased. There is now a need for more profound foresight, more scientific forecasting of the possible course of combat operations, and more accurate calculations of the anticipated results. The timeliness of decision-making and the maximum reduction of the time taken to plan, formulate, and organize the execution of missions have become matters of great moment" [29].

Under the conditions created by the present revolution in science and technology, the selection of the correct direction in the development of arms and military equipment and the adoption within the shortest possible time of soundly based decisions with respect to the development of specific models of weapons and other questions concerned with military affairs present the respective executive, military, and technical agencies with increasingly difficult problems. The scientific and technical revolution has become the basis of a revolution in military affairs. It has an important influence on the development of military equipment, the organizational structure of the armed forces, the methods and forms of combat operations, and the nature of the fighting man's work. Processes

which take place in military affairs are characterized by an increase both in scale and dynamicity. For example, whereas firearms have been in use for almost three centuries and the motorization of the army and navy occurred over decades, the reequipping of modern armies with nuclear missiles has taken a much shorter time. The transition from scientific discovery to practical application of photography took 112 years, the telephone 56 years, radio 35 years, radar 15 years, the atomic bomb 6 years, transistors 5 years, and integrated circuits 3 years.

The difficulties of decisionmaking in various military fields caused by the staggering rapidity and scale of scientific, technical, and industrial development are aggravated still more by the increased cost of modern weapons.

Under these conditions questions of scientifically based military forecasting also take on special importance in those areas of science, technology, and industry that are related to them in some way. The results of scientific forecasting form the basis of plans for the development of the armed forces and of decisionmaking on various military questions by the appropriate competent agencies.

The distinguishing feature of scientific forecasting lies in its being directed at the future. The future is always associated with elements of uncertainty which prevent us from accurately "guessing" a future situation in advance. The basic task of scientific forecasting is to recognize the trend, the logic of the evolution of the process being forecast, thus in the end making it possible to minimize the influence of the uncertainty of a future situation on the results of the decisions adopted.

The present phase in the development of military affairs is characterized by the combined use of various sciences in the solution of military problems. These include the principles of Marxist-Leninist theory, military science, pedagogy, psychology, medicine, cybernetics, mathematics, etc. The penetration of mathematical methods of investigation into military science during World War II marked the beginning of the theory of operations research, which is now developing rapidly.

Mathematical methods of operations research enable us to select the optimal (in one sense or another) variants of decisions regarding the necessary correlations of forces and resources in armed conflict, to calculate material expenditures and losses, and to find the most effective combinations of various means of armed conflict, etc.

But, however efficient and refined various mathematical research methods may be, little benefit will be derived from them if inaccurate input data are used. The very purpose of scientific forecasting is to provide

decisionmaking bodies or individuals with accurate information about what may happen in the future and under what conditions. Thus, only a harmonious combination of modern research methods with the results of scientifically based forecasts and the experience and skill of the appropriate military specialists will enable complex military problems to be solved effectively.

It should be noted that the commander or military leader occupies an important place in the overall scheme of the solution of military problems. The creative activity of a general in troop command and control involves extremely laborious and complex work. "The intellectual activity associated with the top position of commander-in-chief," wrote Clausewitz, "is among the most difficult of activities that fall to the lot of the human mind" [24].* Under present-day conditions the role of the commander or military leader in the process of troop command and control has grown immeasurably. At the same time, he bears more responsibility for the decisions he makes, which in turn places more exacting demands on the professional training of the commander. Not only must the commander have a first-class knowledge of the potentialities of present-day equipment and be able to manage troops in accordance with modern military science, he must also possess an adequate amount of the specialist's knowledge in order to be able to make proper use of forecast data in decisionmaking. "In order to manage any activity," said V. I. Lenin, "it is necessary to be competent . . . to have some scientific education."[1]

The growing interest in questions of forecasting is expressed in the appearance, both in Soviet and foreign publications, of a number of works devoted to various aspects of the problem of forecasting. Among these should be included the work of A. G. Ivakhnenko and V. G. Lapa [21], devoted mainly to the use of cybernetic systems of recognizing models for the solution of forecasting problems, as well as the book by Yu. V. Chuyev, Yu. B. Mikhaylov, and V. I. Kuz'min [62], in which an attempt is made to unify forecasting questions by a single methodology, and which describes several modes and methods of forecasting useful in engineering. B. V. Vasil'yev's book [9] is devoted to a particular forecasting problem.

Among the foreign works we should mention E. Jantsch's book [67], which decribes the status of forecasting in a number of foreign countries, and R. G. Brown's book [70], devoted to problems of exponential smoothing in forecasting. H. Theil's book [55] deals with questions of economic forecasting. In addition to the books listed above, there are a

*[No attempt has been made to verify the precision of the Russian translations of Clausewitz in this book—U.S. Ed.]

great many publications devoted to forecasting problems in various Soviet and foreign periodicals. Of the foreign publications which to one degree or another throw light on questions of military forecasting, we should mention the work of the American author, B. Radwick [42],* a collection of articles edited by J. R. Bright [69], and C. J. Hitch's book [58]. The Soviet literature is completely lacking in books devoted to military forecasting problems, if we discount those by P. G. Skachko et al. [48] and L. S. Semeyko [46], which deal only with certain aspects of these problems.

The aim of the present work is to attempt to present the main results obtained to date in the field of the theory and practice of forecasting as applied to the solution of military problems.

Where possible we have omitted expositions of the proofs of theorems and complex derivations of functions that might create difficulties for users of the book whose mathematical training is at the higher military educational institution level. The reader interested in going more deeply into particular theoretical questions can avail himself of the appropriate works cited in the list of references. The principal theoretical results are, where possible, illustrated by hypothetical numbered examples, as well as by examples taken from open foreign publications. For a variety of reasons these examples are of a purely conventional character and are not intended to be used for developing any particular practical recommendations. They are included simply to help the reader to gain a deeper understanding of the text in question and to enable him to solve practical military forecasting problems more efficiently.

The book consists of two sections. The first, consisting of five chapters, deals with general principles of the military application of forecasting.

The second section, consisting of four chapters, is devoted to the methodology and practice of military forecasting.

The book is intended for a wide range of military readers: officer personnel of military units, staffs, research organizations, and military educational institutions, as well as workers in the defense industry and related educational institutions.

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*[This is only the conjectured spelling of this name. The Russian transliteration is Radvik. Neither the name of the individual nor his book cited on a later page appears in U.S. Library of Congress files—U.S. Ed.]

1. V. I. Lenin, *Poln. sobr. soch.* [Complete Collected Works], XL, 215. [Hereafter cited as Lenin.]

PART I: GENERAL PRINCIPLES OF THE APPLICATION OF FORECASTING IN MILITARY AFFAIRS

Chapter 1. What Forecasting Is

1. Basic Concepts and Definitions

Every future situation is, to a greater or lesser extent, uncertain. We can never know in advance the precise quantitative and qualitative characteristics of a certain event at a specific moment of time in the future—whether it will or will not rain tomorrow at midday, or the qualitative and quantitative composition of the armed forces of a certain state 10 years hence.

The continuing scientific and technical revolution, the staggering rate of scientific and technical progress, the gigantic scale of modern industry, and the ever-accelerating dynamics of life require the appropriate competent agencies and individuals to make, within a limited time, properly substantiated decisions that will have important consequences in the future. One of the means which will enable us to ensure that these decisions are sound and objective is scientifically based forecasting. What is forecasting in general, and military forecasting in particular?

Man has been faced with the need to solve forecasting problems from the very first days of his existence, the cost of forecasting errors frequently being reckoned in lives. Such a high price on the quality of forecasting forced man not only to perfect his weapons, his implements of labor, and his skills in carrying out various operations, but also to study patterns in the behavior of the objects of forecasting (for example, animal habits), in order to minimize the element of chance and reduce the probability of failure (in hunting, for example) to the minimum.

Before starting any practical activity, we picture to ourselves the end results of our labor. Marx, emphasizing man's ability to foresee future

events, wrote: ". . . The poorest architect differs at the very outset from the best bee in that, before constructing a cell of wax, he has already constructed it in his head. At the end of the labor process a result is achieved which already existed in the man's imagination at the beginning of this process. . . ."[1]

As man evolved, improved, and accumulated experience, life itself polished and perfected his remarkable ability to foresee future events, and in this field man has achieved certain successes. For example, it is well known that a trained scientist can often predict (within a certain degree of accuracy, of course) the results of a scientific experiment that has not yet been carried out. The history of wars is rich in examples of brilliant military operations conducted by famous generals whose plans were based on precise foresight of the enemy's behavior in a particular situation.

However, in many cases intuitive forecasts may not always be accurate and objective. This is especially true under present-day conditions, when man has to face increasingly complex and large-scale problems, while the time available for solving these problems is constantly shrinking. This calls for the improvement of old, and the development of new, highly efficient methods and means of forecasting, free of the defects which characterize intuitive forecasting. Mathematical methods of forecasting and modern computers help to eliminate these defects. For example, the landing sites of automatic space stations on the surface of the moon were forecast on the basis of a large number of calculations carried out by modern high-speed computers. The interceptor pilot solves the problem of intercepting an aerial target on the basis of a large amount of data received from various instruments and devices, which are called upon to minimize the effect of the various kinds of uncertainties (maneuvers by the target, jamming and natural interference, etc.) that accompany the performance of the assigned mission.

Thus, we see that the circumstance which gave rise to the forecasting problem and in a number of cases made it extremely complex and laborious **was the presence of uncertainties attending the process being forecast in the past, present, and future.** As a rule, it is not possible to eliminate these uncertainties completely, especially those in the future. The aim of forecasting, which establishes **what may occur in the future and under what conditions,** is to minimize the effect of uncertainties on the results of decisions being undertaken at the present time. This constitutes the basic difference between forecasting and **planning,** the latter determining **what is supposed to occur in the future.**

An examination of various forecasts will make it possible to see their varying **degrees of objectivity.** In this regard let us compare, for example,

the two following forecasts. Having received an order to capture an enemy-occupied inhabited locality in 24 hours, the commander, in working out his combat operations plan, is faced with the necessity of considering (or not considering) a number of factors (air support, the state of the roads and airfields, etc.) which depend on future weather conditions. In principle the commander can make a decision depending on a forecast which he makes himself on the basis of weather conditions at the moment this decision is made. In fact, if 24 hours before the planned combat operations the weather is clear and sunny without a hint of rain, this may seem to the commander sufficient reason (perhaps in many cases justified) for counting on the presence of future air support and the good condition of roads and airfields, etc. On the other hand, if the commander were to base his decision on a weather forecast which predicted overcast skies and heavy rain within 24 hours, then in planning the combat operations he would take into account the lack of air support, poor road and airfield conditions, etc. (perhaps even unjustifiably, since the weather forecast might prove to be wrong).

The first of these forecasts is largely of a **subjective character,** while the second is an **objective forecast,** since it utilizes more complete information (meteorological data) about the weather conditions than a simple observation made 24 hours before the operation and, moreover, it is based on scientific methods. The price of our mistake in relying on a subjective forecast may not be high in many cases. However, if it is a question of making responsible decisions which may have important consequences in the future, then there is an obvious need to rely on objective forecasts.

V. I. Lenin, himself possessing the rare gift of forecasting the future, wrote: "Miraculous prophecy is a fairy tale. But scientific prophecy is a fact."[2]

The current literature contains a fairly large number of terms, definitions, and concepts relating to the problem of forecasting, which, however, are not always treated unambiguously. These include such words as forecasting, prediction (*predskazaniye*),* foresight, recognition, finding out, forecast (*prognoz*), etc. Thus, for example, in the formulation of the Austrian scientist E. Jantsch forecast (*prognoz*) denotes a probabilistic statement about the future with a relatively high degree of reliability, while a prediction (*predskazaniye*) is an apodictic (nonprobabilistic) statement about the future based on absolute reliability [67].

*[This and the following instances where the English term is followed by a *Russian translation* in parentheses represent cases in the original Russian text in which an *English translation* in parentheses follows a Russian term—U.S. Ed.]

Obviously, if we can agree with the first half of the formulation, concerning the probabilistic nature of a forecast, then the possibility of a statement about the future based on "absolute reliability" seems extremely doubtful and, besides, "a relatively high degree of reliability" does not permit the concept of a forecast to be defined unambiguously.

The American expert on forecasting, R. Brown, uses the concept "prediction" (*predskazaniye*) to describe subjective estimates of a future situation, and the concept "forecast" (*prognoz*) to characterize the results of mathematical calculations.

In their work, *Prognostika* [Prognostication] D. M. Gvishiani and V. A. Lisichkin suggest taking prediction to mean foresight of those events whose quantitative characterization is either impossible (at a given level of cognition) or difficult, and taking forecast to mean a statement which registers in the terminology of some linguistic system an unobservable event that satisfies a variety of conditions.

Of necessity the first of these formulations, which suggests that prediction be taken as foresight, requires an explanation. Just what is foresight itself?

The list of formulations concerning the various terms associated with the problem of forecasting could be continued.

Without going into a detailed investigation and analysis of the meanings of all these terms put forward by different authors, we shall introduce the following definitions of the concepts of "prediction," "forecasting," "forecast," and "forecasting system," which we shall be using subsequently.

Prediction is the art of judging the future state of an object, based on the subjective "weighing" of a large number of qualitative and quantitative factors.

Forecasting is a research process, as a result of which we obtain probability data about the future state of the object being forecast.

A forecast is the final result of prediction and forecasting.

A forecasting system is a system which incorporates mathematical, logical, and heuristic elements, into the input of which is fed up-to-the-minute information about the object being forecast, and at the output of which information is obtained about the future state of this object (a forecast).

Forecasts may be **qualitative and quantitative** in content.

Qualitative forecasts may be obtained both by logical reasoning and by quantitative forecasts of processes and phenomena which affect the process being forecast. For example, a qualitative forecast about the nature of a possible armed conflict can be made if forecasts about the qualitative and quantitative composition of the enemy's means of armed conflict are available; it can also be made on the basis of a forecast of the political situation, etc.

A quantitative forecast is associated with the probability of a particular event's occurring in the future and with certain quantitative characteristics of this event (expected value, variance, most probable value, etc.).

We shall distinguish between the concepts of **point** and **interval** forecasts in quantitative forecasting.

By a point forecast is meant an estimate of the expected value of the parameter being forecast at a given moment of time in the future. However, as we have already indicated, we can never accurately "guess" a future situation. Therefore, knowledge of the magnitude of a point forecast is not usually sufficient, and so can be regarded as a center about which certain future events will be grouped according to a certain law. Therefore, in addition to a point forecast, we shall consider an interval forecast, which characterizes the size of the field into which the future value of the process being forecast will fall with a given probability. The geometrical interpretation of these concepts is given in figure 1. This diagram also illustrates other concepts which will be needed in the future.

The observation interval is the time segment [and/or the range of variation of one or more other independent variables] on which there are data (statistics) about the behavior of the forecast magnitude up to the present moment of time.

The lead interval is the time segment from the moment the forecast is made to the moment of time in the future for which the forecast is made.

The forecast time (and values of other independent variables, on which the magnitude being forecast depends) is the moment of time (values of variables) in the future for which the forecast is made.

2. Military Forecasting

Military forecasting takes in a very wide range of questions. These include problems of forecasting the military-political situation and related

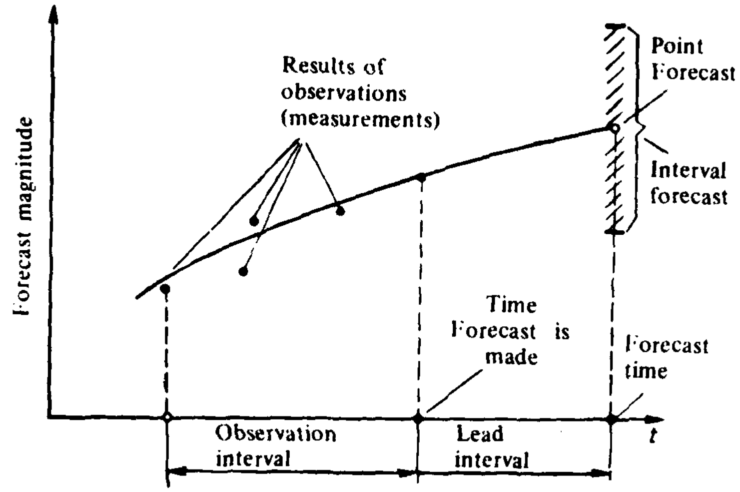

Figure 1. Definition of Point and Interval Forecasts.

problems of forecasting in the fields of strategy, operational art, and tactics, which in turn are related to forecasting the quantity and quality of armed forces and the characteristics of weapons and military equipment. The solution of the indicated problems of forecasting our own magnitudes and parameters is inseparably linked with forecasting the corresponding magnitudes and parameters of the enemy.

Under present-day conditions particular importance attaches to the timely and accurate forecasting of the enemy's strategic and tactical plans and concrete combat operations plans (time, place, missions).

Military forecasting may be distinguished both in terms of scale and lead interval. In fact, there is a need to forecast various indices, quantities, and parameters related to the war as a whole as well as to forecast individual operations, battles, battle episodes, etc. Forecasting procedures in peacetime and in wartime take place under completely different conditions. Military forecasting, as a process by means of which the above indicated problems can be solved, has existed for a long time.

In fact, from the time of their invention, the use of small arms has been based on forecasting the relative positions of the bullet and target. Here the quality of the forecasting (accuracy of firing) depends completely on the rifleman's experience in general, and his familiarity with a given type of weapon in particular.

A fundamental factor in the employment of artillery is the scientific forecasting of the shell's coordinates, based on mathematical methods

employing large quantities of input information (gun and target coordinates, shell characteristics, meteorological conditions, etc.). Firing tables, which are compiled from research on forecasting shell coordinates during a large number of experimental firings, serve as the basis for calculating (forecasting) a given specific shot. The quality of the forecasting (accuracy of firing) in this case depends on the degree of correspondence between the values of the actual parameters (target coordinates, shell characteristics, meteorological factors, etc.) and the values obtained from calculation.

The solution of aerial target interception problems is based both on the mathematical methods underlying the operation of the equipment and instruments involved, and on the experience and personal qualities of the pilot.

Before a battle the commander forecasts its course and outcome. General of the Army P. I. Batov writes the following: "Like every other work of human hands and will, a battle is experienced twice—once in the mind and again in reality. If the chief of staff is the mathematician of the operation, then the army commander must be more than this. He must by the power of imagination, straining the sharp edge of his sense of foresight, experience this first mental battle, whose details at some points are impressed on his memory like stills from a movie" [3].

General of the Army P. N. Lashchenko talks about the correct forecasting of the enemy's probable actions in the following episode:

> Chernyakhovskiy greeted me warmly and simply, emphasizing our long acquaintance. But on the way to the house where the division headquarters was located, he began suddenly in his characteristic joking manner to reproach me for, in his words, pampering the enemy, for not harassing him enough, and for voluntarily letting him have the initiative. He had become insolent, had formed the habit of attacking us daily, if not in the morning, then in the afternoon.
>
> "Now really, can't you give him a good shaking so he'll quieten down and sit still?" teased Ivan Danilovich, looking at me sideways with a sly, provocative grin. . . . "The main thing is to go over everything in your mind, weigh it all up beforehand, keep your eyes open, and everything will turn out as it should be! . . ."
>
> Returning to headquarters, I immediately refined certain data about the enemy and then put forward . . . the concept of the impending operations. . . . Briefly, the plan was as follows.
>
> To regroup our forces in such a way that the entire 4-kilometer Chervonnoye-Kokhanovka sector in which the Hitlerites were attacking us almost daily with forces of as many as two infantry regiments, could be defended by

the 1087th Regiment alone, forming it into two echelons and solidly mining the terrain. Meanwhile the main forces of the division would be concentrated on the Zheludka-Chervonnoye line. As soon as the Hitlerites attacked, as usual, on our left flank, we would deliver a lightning retaliatory strike with the right wing. . . . As the sky lightened in the east we endured agonizing minutes of suspense. What if the enemy had guessed our plan! Supposing he didn't open the attack in his usual way, but directed the spearhead of his attack at our right flank and upset all our calculations! But the Hitlerites suspected nothing! At the appointed time their guns opened up as usual on the left wing of the division. . . . the enemy moved into the attack. Soon two of his infantry regiments were forced into inescapable battle on the approaches to Kokhanovka. At this point our main forces struck swiftly and the results exceeded all expectations. . . . For the Hitlerites the disastrous outcome of the battle was completely unexpected. They were so surprised that they broke off the attack on the 1087th Regiment and, finding themselves under flank attack, . . . began to withdraw hurriedly [30].

In recent times military forecasting has become one of the most important and pressing problems of modern military science. While it is a fully independent division of military science, military forecasting is intimately associated with forecasting in other fields of the life and activities of human society. For example, how could one in practice forecast the prospects for the development of military affairs in isolation from the forecasting of prospects of development in the fields of science and technology, economics, international relations, the numerical strength and composition of populations, etc.? At the same time, military forecasting is characterized by unique features which make it possible to regard it as an independent division of forecasting. We shall dwell in more detail on the singularities of military forecasting below.

The interest now centered on military forecasting abroad and the importance which is ascribed to it are characterized by the words of the American military writer B. Brodie: ". . . The U.S. armed forces make wide use of the data of pure and applied science, not only for the development of new and increasingly sophisticated models of combat equipment, but also to forecast and analyze the tactics and strategy of future wars. . . . When the method of action is derived from scientific tenets, it is more reliable by far than the other, traditional method, based on essentially intuitive judgments and the experience of outstanding military commanders" [7].* The reason for so much attention being paid to forecasting, which has become an independent division of military science

*[The above is a reasonably literal translation of the Russian text. Below follows the same passage, on page 406 of the American edition, published in 1959 by Princeton University Press. The Russian edition fails to note the omission of the short phrase that is presented below in italics. It will be noted that the Soviets made a very few rather liberal changes in adjectives and adverbs, which do not, however, make any radical change in the sense of the passage. (It is frequently the case in Soviet practice to present as quotations

research, is, as we have already indicated above, the scientific and technical revolution and the influence of scientific and technical progress on every aspect of the life of modern society, including military affairs. This influence is expressed, for example, in changes in tactics, in the emergence of a trend toward shorter replacement periods for obsolete models of arms, a tendency for the rate of obsolescence of these models to increase, etc. For example, whereas the American B–29 strategic bomber existed for about 17 years (from the beginning of the 1940's to the middle of the 1950's), the American Atlas intercontinental strategic missile system was operational for approximately 8 years, after which it was replaced by the more refined Minuteman system. The American Thor and Jupiter missile systems came into service at the end of the 1950's, and by the middle of the 1960's they were replaced because of obsolescence. Under present-day conditions it should be expected that the conditions and nature of troop combat operations will differ sharply from those which obtained earlier, particularly during World War II. This difference is expressed primarily in the more dynamic nature of combat and the need to concentrate and disperse troops in the shortest possible time. In this connection, because of the enormous power of modern weapons, the price of a mistake, even a very minor one, increases immeasurably. The consequences of underestimation (errors in forecasts) of the development of air defense facilities by the U.S. military leadership can be demonstrated by the following example. After the end of World War II, intensive work was begun in a number of capitalist countries, particularly in the U.S., on the development of cruise missiles. The main advantages of cruise missiles over ballistic missiles are that they weigh less, consume considerably less fuel, are smaller, and not nearly so costly. In addition, by installing a unit containing intelligence-gathering equipment in place of the warhead, the cruise missile can be used as a means of reconnaissance. The main drawback of cruise missiles is that they are highly vulnerable on account of their comparatively low operational altitude and speed, which makes it easier to detect and destroy them.

Underestimating the prospects of developing air defense facilities, the American leadership allocated vast resources for the development and production of cruise missiles, as a result of which large numbers of these weapons were produced (Loon, Matador, Mace, Regulus I and II, Snark, etc.) which subsequently proved inadequate on account of the development and creation of modern air defense facilities [60]).

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passages which are rather free translations or which are to some degree paraphrased. Note will be made of this at several points in this book.) ". . . The American armed forces are eagerly exploiting science and scientific techniques not only to avail themselves of new military tools of increasingly bizarre characteristics, *the enthusiasm for which is itself a departure from former ways,* but also to predict and analyze the tactics and strategy of future wars. . . . When the method is true to its own scientific tenets, it is bound to be more reliable by far than the traditional alternative method, which is to solicit a consensus of essentially intuitive judgments among experienced commanders."—U.S. Ed.]

All this explains the growth of the role of military forecasting into what it is today.

Thus from what has been said, we can conclude that the **subject of military forecasting** is the study of the military-political situation, the pattern of war in the future, the prospects of developing strategy, operational art, and tactics, the qualitative and quantitative composition of the means of armed conflict (one's own and the enemy's), the prospects for development of the potential of the war economy in the future, and also the forecasting of the enemy's strategic and tactical plans. It should be emphasized once more that all these questions are inseparably linked. In fact, the pattern of future war cannot be considered apart from analysis of the qualitative and quantitative composition of the means of armed conflict, and the latter in turn depend on the prospects of development of the military sectors of industry and the state of the economy at the moments of time in question, etc. The enemy's actual plan of operations can be forecast on the basis of an analysis of the actual situation and by taking the strategic and tactical patterns of his operations into account.

Forecasts are **short-term, medium-term,** and **long-term,** depending on the lead interval (the length of time from the moment a forecast is produced to the moment of time in the future to which it applies).

Forecasts with a lead interval of up to 5 years customarily fall into the short-term category for processes of development, production, etc. Forecasts with lead intervals of 5 to 10 years and over 10 years are considered to be medium-term and long-term, respectively. This categorization with respect to time is, to some extent, arbitrary. However, it does correspond to the practice of forecasting, and is at present generally accepted both in the Soviet Union and abroad. It should be noted that the above lead interval magnitudes, as we have already mentioned, pertain to processes such as the life cycles of models of arms and military equipment, processes in military economics, and other processes of similar duration. However, in military affairs there are processes whose duration is considerably less than the above lead interval magnitudes. For example, processes associated with combat operations may last months, days, or hours; processes involved in guiding missiles to their targets take minutes and seconds. Clearly, for these processes the concepts of short-term, medium-term, and long-term forecasts will be determined by the magnitudes involved. For example, the concepts of the applicable categories of meteorological forecasts are well known. The effect of the length of the lead interval on the characteristics of the forecasts will be examined in detail in the second section of the book. Here we shall content ourselves with noting the commonsense fact that

a forecast becomes less accurate as the lead interval is increased. The fact is that the coordinates of an aerial target 10 seconds hence can be forecast more accurately than, say, one a minute away, since the uncertainties which accompany the process of calculating the coordinates (jamming, measurement and calculation errors, etc.) will have a much more telling effect after 1 minute than after 10 seconds.

The possible characteristics of a prospective weapon model in 3 to 4 years can be estimated with great accuracy by experts concerned with the development and production of this model, since such a forecast is based on the actual state of affairs in the development and production of this model. A long-term forecast of model specifications presents considerable difficulties, if only because first of all it is necessary to know (forecast) precisely how many models will be in service in the period for which the forecast is being made.

This example illustrates the difference in the role played by short-term and long-term forecasts in the system of decisionmaking in military matters. Whereas short-term forecasts, being the most detailed and precise, serve as the basis for working out detailed plans, long-term forecasts, which cannot and should not be as specific and detailed, are simply beacons which illuminate the general direction, the tendency of the process in question. Medium-term forecasts, as the name implies, occupy an intermediate position between short-term and long-term forecasts.

In any discussion of the nature of military forecasting we are inevitably faced with the question of its relationship to **military planning** as the field in which military forecasts are realized. The results of military forecasting serve as a scientific basis for the elaboration of military plans which determine what is supposed to happen at a given moment of time in the future. Military planning is now directly connected with the work of directing the development of the armed forces. At the stage of preparation of responsible decisions and planning work it is essential to maintain the closest relationship between forecasting and mathematical methods of operations research, thus making it possible to formulate optimal (in some particular sense) decisions and plans. Thus, the practicability and quality of military plans depend largely on the accuracy of forecasting results.

History contains many examples of the failure of plans that were based on information which was unreliable or insufficient for sound decisionmaking. The notorious fascist "Barbarossa" Plan failed because it did not take into consideration the potential resources of the Soviet economic system and the great moral and political strength of the Soviet people.

Another well-known example is the miscalculation by the military leadership of the U.S., which dragged the country into a protracted war in Vietnam, and which failed to take into account both the will of the heroic Vietnamese people to resist, and the support of all the freedom-loving nations of the world.

If the agencies or individuals involved adopt a subjectivist approach to decisionmaking and planning and ignore the data provided by accurate forecasts, they can anticipate major problems. An example of this is the French military leaders' disregard of the forecast made by the military experts of a number of countries prior to World War II concerning the diminishing role of powerful permanent defensive installations on account of the development of tanks and aviation. As a result of this the French General Staff planned to deploy the bulk of their armed forces on the Maginot Line, which in their opinion was capable of halting the attack by the German armies. As we all know, these plans were overturned by the realities of history.

Thus, objective consideration of the data provided by scientifically based forecasting when using scientific methods of decisionmaking is the only guarantee against gross errors, and it is only such consideration that ensures the successful execution of military missions.

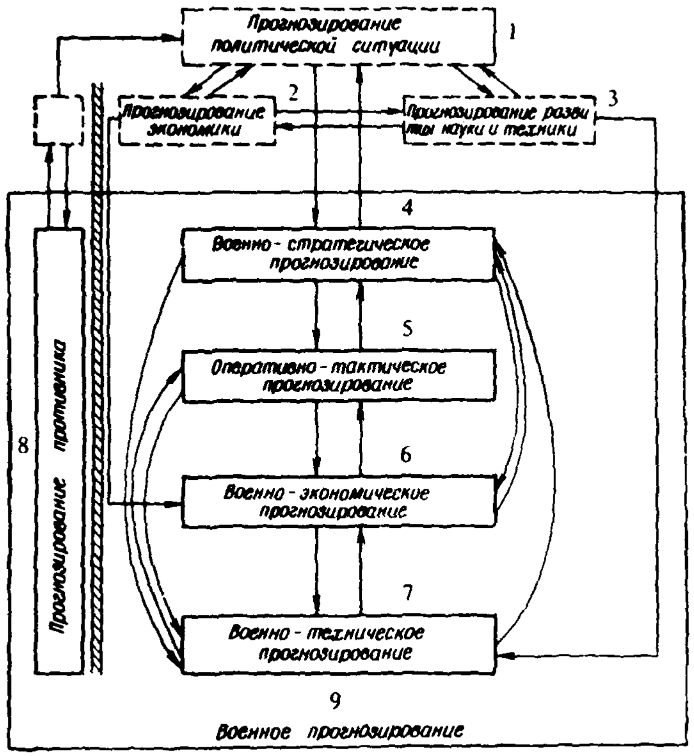
Let us consider the principal aims and fields of application of military forecasting in more detail.

3. The Aims and Fields of Application of Military Forecasting

We have defined the meaning of the subject of military forecasting and demonstrated that under modern conditions, because of the colossal power of modern weapons and the large scale and dynamic nature of processes in military affairs, scientific military forecasting is an objective necessity.

In this section we shall dwell in somewhat greater detail on the purposes and fields of application of military forecasting. We shall cite some examples which reiterate and confirm the necessity of using forecasting in military affairs.

As we have already pointed out, military forecasting is closely related to forecasting in other fields of the life of a modern society. The same can be said about the organic relationship between different fields (di-



Key:
1. Forecasting the political situation
2. Economic forecasting
3. Forecasting the development of science and technology
4. Military-strategic forecasting
5. Operational-tactical forecasting
6. Military-economic forecasting
7. Military-technical forecasting
8. Forecasting the enemy's situation
9. Military forecasting

Figure 2. Types of Forecasting and Their Interrelationship.

visions) and problems of military forecasting itself. Nevertheless, four fields (divisions) of military forecasting can be identified: strategic, operational-tactical, economic, and technical.

Forecasting in the strategic field, which we shall call **military-strategic forecasting,** is associated with the character and means of conducting future wars that may occur, the forecasting of the military objectives, missions, actual plans, and overall composition of the armed forces of individual countries and coalitions. It is not difficult to see that military-strategic forecasting is inseparably linked with and, in turn, influences forecasting of the world political situation. Data used for military-strategic forecasting include the results of operational-tactical, economic and technical, and social forecasting.

The various divisions of military forecasting, their mutual relationships, and their relationships with certain divisions of nonmilitary forecasting are illustrated in figure 2. Military-strategic forecasting provides us with a forecast of the character of a war and methods of waging it under certain conditions determined by a variety of input data, a forecast of the military goals, plans, and tasks with which the armed forces may be confronted under such conditions, etc.

Military-strategic forecasting data provide the input data for **operational-tactical forecasting,** which is concerned with more detailed investigation of future means and methods of conducting combat operations in various theaters of war (based on strategic forecasting data), and with practicable principles of the operational employment (application) of various existing and prospective systems and individual models of weapons and equipment. Mathematical methods of operations research enable us to estimate the combat effectiveness of various methods of waging war with existing and prospective resources in a particular future situation from operational-tactical and military-technical forecasting data. The use of military-technical forecasting data in operational-tactical forecasting makes it possible to forecast new means and methods of conducting combat operations, new organizational structures of subunits, etc., for, in the words of F. Engels, "Hardly had technological achievements been made available and put into actual use in military affairs when, almost forcibly and, moreover, often against the will of the military command, they gave rise to changes and even revolutions in the method of conducting combat. . . ."[3] V. I. Lenin, developing this thought, wrote: "Military tactics depends on the level of military technology. . . ."[4]

Military-economic forecasting, which is inseparable from the forecasting of the economy of the entire country (or even a number of countries linked by common aims and problems), is inextricably bound up

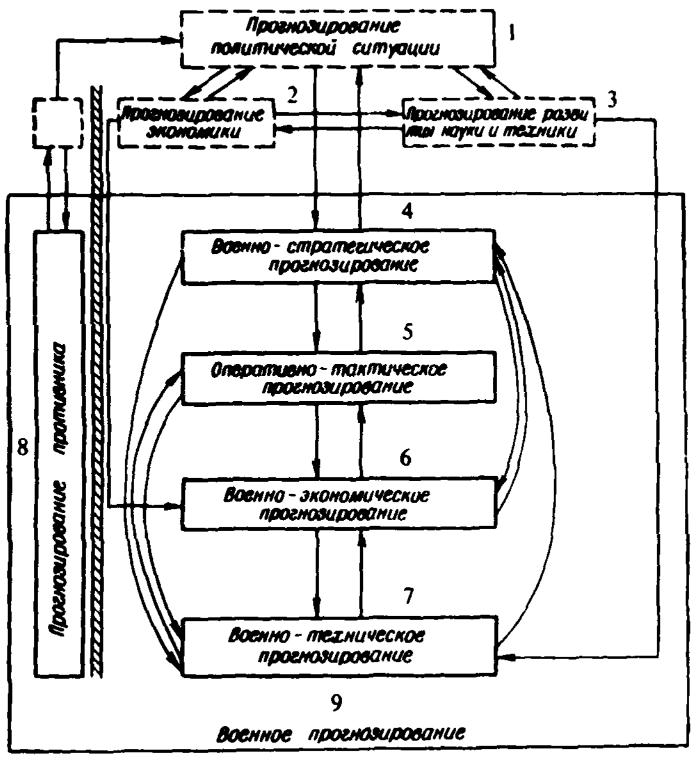


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Figure 2. Types of Forecasting and Their Interrelationship.

with all the divisions of the military forecasting system, since military-economic forecasts form the substance of the input information in these divisions and represent limitations on the support of the armed forces, both in peacetime and in wartime. V. I. Lenin pointed out that the dependence of qualitative and quantitative changes in military technology on the economic resources of the country and the conditions created by the growing momentum of scientific and technical progress is becoming more and more decisive. In particular, analyzing the history of wars in the age of imperialism, V. I. Lenin emphasized that "the relationship between the military organization of the country and its entire economic and cultural structure was never so close as at the present time."[5] He pointed out the need to keep this relationship under constant review in the process of building up the armed forces.

Economic forecast data enable us to solve problems concerning the most effective qualitative and quantitative composition of the armed forces, which could carry out their assigned missions with the minimum expenditure of economic resources (or carry out the maximum number of tasks with the present resources). As we have indicated, economic forecast data, which affect all the divisions of military forecasting, depend, in turn, on the output information of these divisions. Thus, military-strategic forecasting provides the "Military-Economic Forecast" division with data concerning the presence (or absence) and possible nature of an armed conflict as well as the potential and scale of the effect of the use of armed force on the economy of the country (or a number of countries).

Military-technical forecasting provides information about the potential characteristics of models of weapons and military equipment, and the prospects for development of particular weapon types and systems. In conjunction with economic forecasting, it enables us to obtain information about the technical-economic characteristics of models of military equipment. The input data for a military-technical forecast are the results of research on ways of developing science, technology, and industry. Military-technical forecasting exerts a considerable influence on all the other divisions of military forecasting. The influence of military-technical forecasting on operational-tactical forecasting and the reasons for this have already been considered above. Military-technical forecasting has just as great an effect on military-strategic forecasting. In fact, the employment of modern weapons, for example, changes the spatial scale of armed conflict, and poses the question of surprise and the initial period of a war in a new way. In nuclear missile warfare there is no distinction between the front and the rear. The interrelationship of strategy, operational art, and tactics is changing qualitatively. Whereas during past wars the stra-

tegic goals of military operations were achieved, as a rule, by the cumulative effect of tactical and operational successes, today the higher military-political leadership of the state has at its disposal a powerful means of achieving its principal war aims directly, namely, strategic nuclear missile weapons. Military-technical forecasting is thus, by virtue of its special nature, the most rapidly developing division of military forecasting. If we consider the fact that all the enumerated divisions of military forecasting provide for forecasting not only our own processes and characteristics, but also those of the enemy (which, for a variety of reasons, is an even more difficult task), we can appreciate the complexity of the problems which military forecasting is called upon to resolve. And if we take into account the responsibility borne by the respective agencies which use forecast data for making important decisions, it becomes obvious that military forecasting must be strictly scientific and utilize the achievements of modern computer technology in order to mechanize the work-intensive stages of this process to the maximum extent.

We shall now consider some military problems which it would be inconceivable to resolve without forecasting.

The tasks of military art. Military leaders have always been faced with the need to forecast the course of combat operations. The results of an armed conflict depend largely on the successful solution of this problem. In past wars, when arms, tactics, and troop organization were comparatively simple, and the scale of hostilities small, decisions did not necessitate complex calculations, and their correctness was determined mainly by the experience and military capabilities (talent) of the generals, although even here detailed analysis of a large number of factors determining the combat situation was required. As combat operations increased in scale and became more dynamic, as weapons and military equipment became more sophisticated, so the need for detailed scientific forecasting of the course of combat operations became increasingly acute. Nowadays automation is widely used in the sphere of troop command and control. Its penetration into this sphere of military affairs is expressed in the development of various automated control systems which make wide use of electronic computers. The introduction of such systems is necessitated by the short time available to all control elements because of the great speeds of modern weapons, the possibility of rapid changes in the situation on the battlefield because of the use of such weapons, and the enormous scale and short duration of combat operations.

Mathematical methods of operations research enable us to formulate control algorithms, to compare the effectiveness of different versions of control algorithms, to select the best one, and to introduce into them the necessary changes in the process of using automated control systems.

Automated control systems need information, but it must be accurate, for however perfect these systems may be, if the information fed into them is inaccurate, they will be of little use. And it is quite obvious that, even in the absence of automated control, accurate forecast information is no less necessary. Thus, the thesis "to lead means to foresee" acquires special importance under present-day conditions.

The task of selecting optimal methods for the combat employment of new weapons models. Scientific methods of forecasting occupy an important place in the selection of optimal methods for the combat employment of new models of weapons. This is a very difficult task in peacetime. Its successful solution depends upon a correct forecast of the possible methods for the combat employment of new weapons and methods of conducting combat operations. It is possible to estimate the effectiveness of a particular method of employment and to select the best one on the basis of forecast data associated with range tests, exercises, and war games. Forecast data also provide the basis for solving the problem of determining the effect of a new weapon on methods of the combat employment of an old one (redistribution of tasks) and, in consequence, the expediency of retaining an old weapon.

The task of selecting optimal methods for countering a new enemy weapon is similar to the one above.

Thus, we can again be certain that forecasting tasks are organically related to other military problems.

Tasks in the operational and combat training of troops. The solution of the problem of maintaining troops in a state of constant combat readiness is determined largely by the successful solution of the problem of their peacetime training. This task is complicated by the absence of a real enemy and by a number of conventions in the conduct of war games and exercises. Under these conditions military forecasting takes on special significance, since it affords a means of selecting a region corresponding to a probable future theater of operations in which the troops master methods of conducting combat operations under actual geographical and climatic conditions.

In such a case special importance attaches to forecasting the enemy situation (the organizational structure, the quantitative and qualitative composition of his armed forces, etc.) as well as the means and type of future combat operations. The quality of troop combat training in peacetime depends largely on the accuracy of such forecasts. These are the tasks of combat training as seen by General of the Army V. G. Kulikov:

In perfecting the combat readiness of military and naval forces there can be no limit. It is necessary to raise constantly the standard of training, knowledge, and skill of the personnel; to keep pace with the development of military science; to systematically introduce into combat training new problems arising in connection with the appearance of new types of weapons and equipment; to respond correctly to changes occurring in the military-political situation, in the state of the armies of a probable enemy, and in the equipment of theaters of operations [29].

The direction and quality of the psychological training of personnel also depend upon the accuracy of forecasts of the enemy's use of a particular weapon.

Military-technical tasks. If we consider the high cost and lengthy periods of development of modern weapons, we can at once see how important it is to solve problems relating to the expediency of developing new models of weapons and to the optimal performance characteristics of these models. Here it is also perfectly obvious that operational-tactical, military-strategic, military-economic, and military-technical forecast data are absolutely essential. Thus, for example, in developing models of antiaircraft artillery, we must take into consideration a hypothesis on the nature of the movement of enemy aerial targets based on appropriate forecasts of the specifications and the tactics of employment of these targets.

The list of military problems for whose solution scientifically based military forecast data are organically necessary could be further extended. However, the problems we have enumerated so far are sufficient to demonstrate the enormously increased importance of military forecasting, which, under present-day conditions, makes it an independent branch of military-scientific research.

4. Marxist-Leninist Theory and Forecasting

A knowledge of Marxist-Leninist theory is an indispensable condition of scientific forecasting of the future. V. I. Lenin taught that dialectical and historical materialism is the only correct methodology of knowledge, without which our deductions and generalizations would be feeble, and errors and miscalculations in assessing a future situation would be unavoidable.

The feasibility of truly scientific forecasting is based on the dialectical materialist principles of objectiveness, regularities in the evolution of nature and society, and the possibility of knowing the world around us. Considering the indicated principle of objectiveness, we note the ex-

tremely important and fundamental Leninist requirement for a concrete historical approach to the analysis of world phenomena, which is of enormous methodological importance for scientific forecasting.

Marxism as a science, wrote V. I. Lenin, places all questions of the development of society on ". . . a historical basis, not in the sense of a single explanation of the past only, but in the sense of fearless foresight of the future and bold, practical work directed at its realization. . . ."[6]

In fact, the only basis for scientific foresight of a given phenomenon or process is a detailed analysis of the actual historical facts and events in their mutual relationship.

Emphasizing the close interrelationship of the past with the present and the future, V. I. Lenin said: ". . . I looked back at the past only from the point of view of what would be needed tomorrow or the day after for our policies."[7]

The fact that there are evolutionary patterns in nature and society makes the scientific forecasting of a future situation possible in principle. Despite numerous uncertainties and chance occurrences, the objective regularities which characterize military affairs make it possible to forecast the course and outcome of military conflicts, and to plan the development of war materiel, etc. The work of fighting men can be effectively organized only on the basis of a knowledge of the laws of armed conflict, methods of command and control, and the ways and means of training and indoctrinating military personnel.

"The laws of the external world, of nature, . . ." wrote V. I. Lenin, "form the basis of the *goal-directed* activities of man. In his practical activities man has an objective world before him, he depends upon it, and his activities are determined by it."[8]

Thus, the existence of laws in the evolution of nature and society forms the objective basis for scientific forecasting. However, it is not sufficient to know that there are objective laws in nature. They must be comprehended. Only a knowledge of the objective laws of the evolution of nature and society turns the objective possibility of scientific forecasting into an actual possibility. To understand the law of development of a phenomenon is to have control of it. Thus, for example, the law according to which changes in weapons and combat equipment inevitably lead to changes in the methods and forms of conducting combat operations enables us to foresee changes in the nature of battles, operations, and war as a whole. And, although objective laws do not depend on human will, people, in cognizing them, may change the conditions under

which these laws are manifested, and limit or give full scope for their action. V. I. Lenin taught: ". . . Until we know a law of nature, it will, existing and acting apart from and beyond our cognition, make us slaves of 'blind necessity.' Once we know this law, which operates (as Marx repeated thousands of times) *independently* of our will and consciousness, we are masters of nature."[9]

A necessary condition of accurate forecasting is a detailed study and penetration into the essence of the phenomenon in question and the concretization of the questions under consideration. V. I. Lenin considered concreteness one of the conditions of scientific forecasting.

"It is impossible to understand anything in our struggle," he wrote, "if we do not analyze the concrete situation of each battle."[10] Of crucial importance for scientific forecasting are the laws of the **development** of nature and society, without the knowledge of which the forecasting of a future situation would be impossible. The dialectical concept of development assumes as the source of development the presence of diverse contradictions within the phenomena and processes themselves. For example, contradictions often occur in military affairs between the latest means of waging war and the established forms and methods of combat operations, the study of which makes it possible to forecast future changes in the indicated means, forms, and methods.

As early as 1919 V. I. Lenin anticipated the possibility of using aviation against ground forces. In September 1919, having in mind the lifting of the threat to Moscow posed by General Mamontov's cavalry, V. I. Lenin gave the order to the Revolutionary Military Council of the Republic: ". . . *Cavalry* is helpless against low-flying aircraft. . . . Cannot you order some military *scholar* such as X, Y, or Z . . . [to provide] an answer (quickly): Airplanes against cavalry? *For example. Very low* flight. *For example. . . .*"[11]

In accordance with V. I. Lenin's instruction, despite the misgivings of some military specialists, the Revolutionary Military Council formed a special-purpose air group, which carried out Lenin's directive and delivered a number of successful attacks on Mamontov's cavalry.

The methodological basis of scientific forecasting is the Marxist-Leninist theory of knowledge developed by V. I. Lenin, according to which, not only is knowledge of the past and present possible, but knowledge of the future, as well, since in principle there are no unknowable things, phenomena, or processes, but only things, phenomena, and processes that are not yet comprehended (or not yet fully comprehended). Scientific forecasting is the process that provides the solution to the problem of comprehending the future. Lenin gave definitions to such vitally impor-

tant concepts in the theory of knowledge as truth and the criterion of truth. The most important principle for scientific forecasting is that the criterion of truth in general and in scientific forecasting in particular is practice. Lenin wrote: "The point of view of life, or practice, should be the first and basic point of view of the theory of knowledge."[12] When it comes to military matters, the comprehensive practice is war. The various exercises and maneuvers conducted in peacetime, although they serve only as partial criteria of the truthfulness of opinions on given military problems, because of the limitations of peacetime practice, are, nevertheless, extremely important. All that is necessary is that training conventions should be reduced to a minimum during combat training, because then the practical activities of troops in peacetime can be an important factor in verifying the truth of forecasts about the nature and special features of a future war.

Let us consider one important feature of scientific forecasting—its probabilistic character. V. I. Lenin, referring in particular to social forecasting, pointed out that in the processes of social life, in which a great many subjective factors exist alongside laws that operate objectively, it is in principle impossible to guess a future situation absolutely accurately. In particular, he wrote: "It would be ridiculous to try to predict the exact dates and forms of future advances of the revolution."[13] As an example, Lenin quoted Marx's approach to the foresight of future events: "Marx makes not the slightest attempt to construct utopias, or to make futile guesses about what cannot be known. Marx poses the question of communism as a naturalist would formulate a question of the development of, let us say, a new biological variant, since we know that somehow it appeared and is undergoing a modification in some specific direction."[14]

In military affairs, where the problem of uncertainties is of a particularly acute character (in many cases artificial), forecasting also has a pronounced probabilistic character. In addition to the "objective" uncertainties which are inherent in nonmilitary processes and phenomena, military personnel have to contend with uncertainties, difficulties, false information, etc., created artificially (by the enemy), which makes military forecasting one of the most difficult and work-intensive divisions of scientific forecasting.

One of the focal problems of forecasting is that of forecasting abrupt changes* in the development of the process being forecast, for, in V. I. Lenin's words, "life and development in nature manifest both a slow evolution and rapid leaps, interruptions of gradualness."[15]

*[The two Russian terms which mean literally "jumps" and "jump-type changes" are both given in this translation as "abrupt changes"—U.S. Ed.]

Thus, a forecast must provide systematically for the possibility of determining both the characteristics of evolutionary development and the parameters of abrupt changes, otherwise objective conditions will be created for gross forecasting errors. Underlining the importance of this factor, V. I. Lenin wrote: ". . . Dialectics differs essentially from the vulgar 'theory' of evolution, which is constructed wholly on the principle that there are no abrupt changes either in nature or in history and that all changes in the world take place gradually. Even Hegel demonstrated that the doctrine of evolution understood in this way is ridiculous and inconsistent. . . ."[16]

V. I. Lenin, for example, brilliantly foresaw the moment at which the October Armed Revolt would begin. Thus, the forecasting of abrupt changes in a great many fundamentally important questions, at least at the heuristic level, made it possible to solve correctly the vital problems of practice. Hence, it is theoretically possible, and therefore necessary, to devise quantitative methods of forecasting abrupt changes.

From what has been said so far, it becomes clear that a sound mastery of Marxist-Leninist theory is essential if we are to resolve successfully military forecasting problems, which are of particular importance today, when the role of scientific troop command and control has expanded as never before. Here it is appropriate to quote the words of M. V. Frunze: "The Red commander must exert every effort to master the method of thinking, the art of analyzing phenomena, expounded by the Marxist doctrine."[17] The knowledge and ability to apply this teaching correctly in practice is a guarantee of the successful resolution of those important tasks which face the armed forces.

NOTES

1. K. Marx, F. Engels, *Soch.* [Works], XXIII, 189. [Hereafter cited as Marx, Engels.]
2. Lenin, XXXVI, 472.
3. Marx, Engels, XX, 176.
4. Lenin, XIII, 374.
5. Lenin, IX, 156.
6. Lenin, XXVI, 75.
7. Lenin, XXXVIII, 136.
8. Lenin, XXIX, 169–70.
9. Lenin, XVIII, 198.
10. Lenin, VIII, 400.
11. V. I. Lenin, *Voyennaya perepiska 1917–1922 gg.* [War Correspondence, 1917–1922] (Moscow: Voyenizdat, 1966), p. 219.
12. Lenin, XVIII, 145.
13. Lenin, XII, 350
14. Lenin, XXXIII, 85.
15. Lenin, XX, 66.
16. Lenin, XXIX, 456.
17. M. V. Frunze, *Izbr. proizv.* [Selected Works] (Moscow: Voyenizdat, 1957), II, 47.

Chapter 2. General Outline of Forecasting

1. General Remarks

In the preceding chapter we examined the question of what is meant by forecasting in general and military forecasting in particular. We defined the concepts of "forecasting," "prediction," "forecast," "forecasting system," and several terms, such as lead interval, forecasting time, etc., which are more specialized but necessary for an accurate mathematical formulation of the problem.

In this chapter we shall dwell in more detail on a description of the forecasting system and its basic elements, and we shall examine questions relating to the interaction of these elements in the process of the formation of the output signal of the forecasting system—the forecast of the required value of the process in question (the object of forecasting). After examining the general outline of the forecasting system, we shall discuss the information that constitutes the input for the system and define the requirements which this information should meet. At the conclusion of this chapter we shall formulate the general requirements which the forecasting system itself must satisfy and examine the criteria which are used in forecasting to obtain the best (in some sense of the word) forecasts.

2. The Forecasting System

Let us move on now to a consideration of the forecasting system. A block diagram of the system is shown in figure 3.

At the outset of this discussion of the general outline of a forecasting system, we shall assume that the object of the forecast has been precisely defined. In other words, we have a clear idea of the kind of information about the future condition of the object (process or phenomenon) we wish to obtain. Although at first glance this remark may seem trivial,

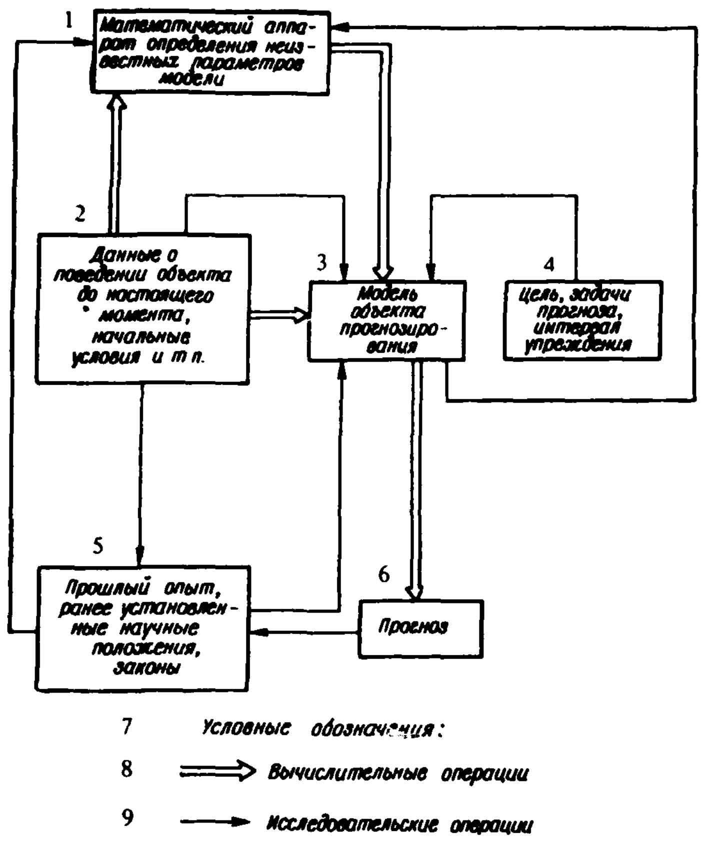

Figure 3. Block Diagram of Forecasting System.

Key:
1. Mathematical system for determining unknown parameters in the model
2. Data on the behavior of the object up to present moment, initial conditions, etc.
3. Model of the object of the forecast
4. The objective, tasks of the forecast, lead interval
5. Past experience, previously established scientific theses, laws
6. Forecast
7. Legend:
8. Computerized operations
9. Research operations

practice shows that the successful solution of a forecasting problem depends largely on a precise definition of the object of the forecast, which is the input for the forecasting system. Correct formulation of the problem is as important in forecasting as it is in other fields of the scientific investigation of human activities. Noting this fact, W. R. Ashby wrote: ". . . When we are able to formulate a problem with absolute precision, we shall be close to its solution."

So let us assume that the object of the forecast has been precisely defined. In the most general case the sequence of operations in forecasting is as follows: information analysis—construction of a model of the object being forecast—determination of unknown model parameters—calculation of forecast for required lead interval—estimate of forecast errors.[1] Let us examine in more detail how this sequence of actions is carried out in the forecasting system. The first obvious step in resolving a forecasting problem is the collection and analysis of information about the object of the forecast. This information may contain data about the past and present behavior of the given object of the forecast, as well as information about the past and present behavior of similar objects. Here the concepts "similar object(s)" and "prototype" should be defined in each specific case by the appropriate experts, since the use of substandard information will not result in an accurate forecast, no matter how well-designed and efficient the remaining elements of the forecasting system may be. We shall dwell in more detail on source information requirements in the next section. Under the heading of necessary information we shall also include previously established scientific principles and the behavior patterns of similar objects in similar situations. It should be noted that a decision on the feasibility of applying a previously established scientific principle or law to the object of the forecast in question must also be made by experienced specialists, since the fields of application of a particular scientific principle or law are limited in the general case, and these limits are not always precisely defined. Thus, the basis for the forecast is the indicated past information. The importance of this past information is well illustrated by W. R. Ashby, who said that in itself "foresight is by its nature an operation on the past." Nevertheless this apt definition of the meaning of forecasting, particularly the expression "operation on the past," needs to be analyzed in more detail. Reasoning from the Marxist-Leninist conception of regularity in the evolution of nature and society, we can conclude that the principal aim of the indicated "operation on the past" or, in other words, the task of analyzing existing information about the object of the forecast, is to determine (recognize) those established patterns which accompany the phenomenon or process under investigation (which are included in the object of the forecast). The successful solution of this problem is equivalent to the successful solution of the forecasting problem, otherwise we are deprived of the possibility for scientific forecasting. Thus, if past information is the basis for fore-

casting, determination of established patterns in the development of the process or phenomenon in question is the focal question of the research part of the forecasting process.

Certain established patterns of phenomena and processes have now been sufficiently well studied and so we are able to deal effectively with problems of forecasting such phenomena and processes. For example, ballistics, which is the study of the dynamics of projectiles developed on the basis of mechanics, provides us with the means of mastering the problem of forecasting the trajectory of an artillery shell, the key to the successful accomplishment of artillery combat missions. The accurate forecasting of ballistic missile trajectories—made possible by the achievements of the modern theory of flight, by automatic control theory, and by modern computer technology—has made ballistic missiles one of the most formidable types of weapons possessed by modern armies. Other established patterns, associated with, for example, military-economic forecasting processes, are by no means always obvious and known, and painstaking special research is needed in these fields to find and reveal them.

The recognition and study of established patterns enables us to construct models (physical and, particularly important for a number of reasons, mathematical models) of the phenomena and processes in question, thus enabling us to utilize the achievements of modern computer technology to solve forecast problems. As we can see from an examination of the block diagram, the selection of the model of the object of the forecast is influenced by the forecast objective and tasks, and by the lead interval as well. The influence of the forecast objective and tasks on the selection of the model can be illustrated as follows. If we are concerned with forecasting the trajectory of the center of mass of an artillery shell in the air, where the axis of the shell at a given moment in time coincides with the velocity vector of the center of mass and the air resistance is directed tangentially in a sense opposite to the direction of the velocity, we can use the established equations of particle dynamics in a given system of coordinates. Note that the assumptions indicated form part of the assumptions used in resolving the main problem of external ballistics. If, however, we are interested in, for example, a forecast of the trajectory of a guided ballistic missile with an inertial guidance system, then in addition to equations which describe the movement of its center of mass, the mathematical model should contain equations of the movement of the missile around the center of mass, since in this case, as one of the additional problems, we should consider the additional forces (from the rotation of the missile) acting on the inertial sensing elements (accelerometers), which, as a rule, are not located at the missile's center of mass. The lead interval can also have a considerable influence on the choice

of a model. A gunner firing at a target flying overhead is "guided" by the hypothesis that a bullet travels in a straight line (in a system of coordinates related to the earth) from the moment it leaves the gun until it meets the target (the lead interval being equal to the time taken by the bullet to travel from the gun to the target). However, it never enters anyone's head to extend the given model to lead times significantly greater than the one in question, since this would be tantamount to assuming that, if the bullet missed its target, it would never return to earth. Obviously, in the second case we should use as a model the differential equations of the motion of an arbitrarily shaped rigid body in air for given initial conditions (given initial velocity vector and coordinates) in a given gravitational field. A model of an enemy's probable actions is selected on the basis of certain indications obtained by studying and analyzing various kinds of information about the enemy. Let us assume that the enemy on a given sector of the front is preparing to carry out offensive operations. His intentions in this respect can be gauged from such indications as the regrouping of his forces, increased reconnaissance activity, the placing of his aviation and missile forces in an advanced state of combat readiness, etc. By analyzing this information the commander and his staff can discover the enemy's plan in good time and on the basis of experience (using already existing models of preparation for an offensive) forecast the probable time at which the enemy will start active operations, thus making it possible to break up his offensive by taking the necessary countermeasures. Thus, given a certain lead time (since the enemy cannot change his plan and regroup his forces instantaneously), the forecast of the enemy offensive will be accurate. However, it would be naive to assume that the enemy, who would also be observing and analyzing our actions, would hold to his former offensive tactics (would not change the model of his actions), having seen that, because of the timely adoption of countermeasures by the other side, the success of his offensive operation had become problematical. This example thus illustrates the influence of the lead time on the selection of a model in terms of the mobility characteristic (time constant) of the process in question, which is of particular importance in processes of conflict between two sides (in game situations).

We shall dwell in more detail on models applicable to military situations in the fourth chapter. Here we shall simply note the fact that, having determined the type of model of the process being forecast, we are usually faced with the problem of determining certain of its unknown parameters, and this involves the use of some type of mathematical system. In particular, extensive use is made of the mathematical system employing the least squares method. More will be said about this method when we examine the criteria used in forecasting. With the selection of the mathematical system for determining the unknown parameters of the

model, the exploratory part of the forecasting process temporarily comes to an end, and the production of the forecast is then, in chess terminology, a matter of technique.

The results obtained from forecasting are subjected to logical analysis, and, as a result of this, corrections can be introduced into the remaining elements or units of the forecasting system, should the forecasting results prove contrary to common sense or scientific principles and laws that have been verified in practice. If, for example, the speed of a future aircraft, according to a forecast, turned out to be faster than the speed of light, this would indicate that an error was made somewhere in the system. This could be due to an incorrectly selected model (which would be most likely), errors in the initial statistics, or computational errors. Analysis of the forecast results is thus the feedback in the forecasting system which makes it closed to forecasting errors.

Having considered the general outline of a forecasting system, we shall sum up under what conditions and demands made on its elements for given input objectives, forecasting tasks, and lead intervals the resulting forecasts can be expected to have the required degree of accuracy.

We have already spoken about the fact that **information about the object of the forecast must be relevant to the forecast objective and tasks, as well as possess the required degree of accuracy.** Actually, in forecasting the trajectory of an artillery shell, for example, the accuracy of our knowledge of the parameters of the shell, its muzzle velocity and angle of departure, and the meteorological conditions must match the required accuracy of the forecast. In order to forecast the course and outcome of the battle accurately, a commander needs timely and accurate information about the composition and state of the enemy forces. In forecasting the flight performance characteristics of a future fighter aircraft we shall not be able to obtain an accurate forecast if data for the corresponding characteristics of, say, civil transport aircraft, are mixed with the statistics in question. Although this example is oversimplified, it does serve to demonstrate the need for careful refinement of the information accepted for the solution of a forecasting problem, and, as practice shows, in some cases the problem of refining statistics is very complex and special research is needed for its solution.

As follows from the foregoing, the next condition of forecast accuracy is **the correct selection of the model (the condition of adequacy of the mathematical model for the phenomenon to be studied).** This is the focal question of the scientific research part of the forecasting process and it can be successfully solved only if the investigator acquires a deep insight into the phenomenon being studied.

Finally, an extremely important requirement is **the correct selection of the estimate criterion for unknown parameters of the model and the corresponding mathematical system,** which ensures the necessary quality of the calculations. Later on we shall give examples of the use of different mathematical methods in forecasting problems.

3. Necessary Information

It follows from the foregoing that the basis for forecasting is currently available information about the object of the forecast.

Depending on the time of receipt, the information needed for the solution of an assigned forecasting problem, may be **a priori, worked out directly in the process of solving the forecasting problem, or a combination of both.**

Examples of a priori information are to be found in different existing scientific principles and laws that describe the behavior of similar objects in similar situations. In military affairs a priori information is provided by the enemy's regulations and instructions and his methods of conducting combat operations as they have been established up to the time at hand, etc. A commander directing the combat operations of his subunit uses information **coming in** continuously from the battlefield. In conflict situations, including combat operations, continuously incoming information is of great value (if there is sufficient time for its realization), since it is closer (in the course of the battle) to the moment of time for which the forecast is being made (the outcome of the battle) than a priori information (prior to the battle).

In terms of completeness information about the object of forecasting can be divided into **incomplete, complete, and surplus.**

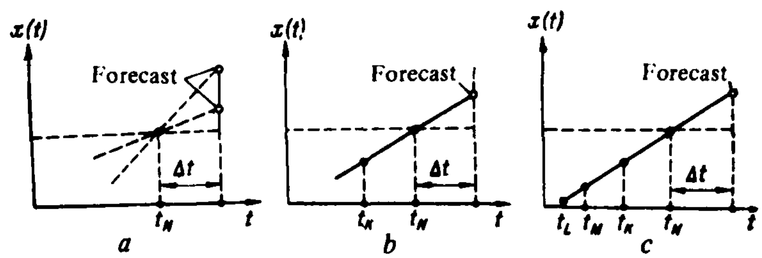

Figure 4. Determining the Degree of Completeness of Information.

We shall take incomplete information to mean information that is inadequate for the solution of the assigned forecasting problem in general, or inadequate for the solution of the indicated problem with the required degree of accuracy.

We shall take complete information to mean information that is necessary and sufficient for the solution of the assigned forecasting problem with the required degree of accuracy. Any other information (in addition to complete information) will be surplus.

Let us illustrate these concepts with a very simple example.

Example 1. Let us assume that we know that the parameter of a certain process $x(t)$ develops (increases) **in a strictly linear fashion with time.** In other words, we know that its model is

$$x(t) = a_0 + a_1 t + \eta \quad (\eta \equiv 0).$$

The forecast problem is to determine its value at moment of time $t_N + \Delta t$, where Δt is the lead interval. Then knowledge of the model and of the values of the process at two points—moments of time t_N, t_K (figure 4*b*)—is complete information, since it enables us to forecast unambiguously the value of the process at moment of time $t_N + \Delta t$. On the other hand, it is not difficult to see that the case represented by figure 4*a* (knowledge of the value of the process at moment of time t_N only) is a case of incomplete information, while figure 4*c* (knowledge of the value of the process at moments of time t_N, t_K, t_M, t_L) is a case of surplus information. In this case we are considering a deterministic (nonrandom) process (since $\eta = 0$) and there are no information errors. In the event that information about the value of the process contains errors, then not only *b* but also *c* may prove to be a case of incomplete information.

We note that surplus information can be subdivided into **partial surplus** and **complete surplus** information. Complete surplus information makes it possible to duplicate in full the solution of the assigned problem.

Turning again to the previous example, it can easily be established that knowledge of the value of the process additionally at moment of time t_M is partial surplus information, whereas knowledge of the value of the process at moment of time t_L is complete surplus information, since at two points $[x(t_L)$ and $x(t_M)]$ we shall determine the value of the process being forecast at moment of time $t_N + \Delta t$, without using information about the values of the process at moments t_N and t_K. The degree of completeness of the information may change with the passage of time. Whereas at moment of time t_L (Example 1) the information was actually incomplete, at moment t_M it had become complete, while at moment t_K it was already surplus.

It should be noted that in solving actual practical forecasting problems in which the process in question is accompanied by uncertainties, cases of surplus information are encountered only infrequently (cases of complete surplus information even less frequently), and the investigator has to make do with complete or even incomplete information. In the latter case he has to take special steps (carry out additional investigations, obtain additional information) in order to solve the assigned forecasting

problem. However, surplus information of one sort or another is always desirable, since in most cases (with the exception of deterministic cases of the type given in the above example) it makes it possible to increase the accuracy of the forecast. Information can be divided into two types—**continuous** and **discrete**—the type of information depending largely on the type of process or phenomenon which it describes.

Processes or phenomena which are subject to forecasting can be either continuous or discrete.

An example of a continuous process is the variation with time of the current coordinates of a moving ballistic missile. Information about continuous processes can be both continuous and discrete. An example of continuous information about a continuous process is provided by the oscillographic recording of loads exerted on a piece of equipment mounted on a moving object. Continuous information is more complete than discrete information. Discrete information about a continuous process is obtained in cases where for one reason or another it is not possible or necessary to obtain continuous information. Thus, for example, discrete information about the coordinates of a ballistic missile may be the consequence of the discreteness of the system of measuring these coordinates, i.e., in this case it is simply not possible to make a continuous recording of the coordinates. On the other hand, the continuous value of parameters of the process being forecast will sometimes be surplus information. For example, in laying down artillery fire from an indirect fire position there is no need for continuous measurement of the surface pressure for the solution of the assigned problem with a predetermined degree of accuracy.

As examples of a discrete process we can cite the number of targets entering the zone of a certain air defense system, the amount of equipment of a certain type entering a base, etc. These magnitudes can be described by certain finite quantities in certain time segments. If processes of this kind are observed continuously, then it is possible that during certain segments of time no information would be received that could be recorded. For example, it is possible that during the course of 24 hours not a single piece of equipment would enter a base. Therefore, as a rule, for discrete processes the total number of observed units (pulses) for fixed time intervals is recorded. An example of this might be the number of models of a given type of equipment delivered to a base during the course of a week, month, year, etc. For this reason a forecast of discrete processes generally defines the total number of pulses during certain (set) time segments in the future, whereas a forecast of a continuous process characterizes the state of this process at some set moment of time in the future.

Considering the question of information about the object being forecast, we should emphasize once more the factor which, in principle, has made forecasting a complex scientific problem. We are referring to the uncertainties, disturbances, obstacles, etc., which attend the process or phenomenon being forecast. These uncertainties stem from the impossibility, at a given stage of investigations, of gaining an insight into the nature of the phenomenon or process being forecast. The difficulties which make it impossible to gain a complete insight into the essence of a phenomenon may be the consequences of insufficient progress in a particular branch of science or technology, economic considerations, or artificially introduced factors such as disinformation or restriction of information by the enemy.

Thus, an imperfection in a ballistic missile coordinate measuring system, which is expressed by the presence of random errors in this system, prevents us from knowing the true position of the missile in the selected system of coordinates and makes it impossible to forecast the position of this missile accurately at a given moment of time in the future. In some cases, although it may be technically possible to construct an accurate forecasting system, this cannot be done on account of economic constraints and thus we have to be satisfied with forecasts of lesser accuracy. And, finally, the third cause of difficulties in forecasting, especially characteristic of military forecasting, is action on the part of the enemy. The enemy always conceals his plans carefully and tries to disinform and mislead his adversary. Thus, information about an enemy is fraught with uncertainties, and correct situation forecasting and error-free decisions require commanders not only to display profound knowledge but to make maximum use of all their military art and their prediction and forecasting capability.

Thus, the most important task in forecasting, as we have already indicated, is the analysis and appropriate processing of information, the removal from it of all kinds of distorting "impurities." Thus, to increase the accuracy of ballistic missile coordinate measurements, it is necessary to refine the coordinate measuring system by reducing its random errors. For example, before making a decision about the need to modify the engine of a motor vehicle on the basis of information about its faults, information about faults resulting from the improper operation of this engine should be excluded from the statistical information at hand.

Before carrying out a planned operation it is necessary for the commander to thoroughly analyze data from various intelligence sources, so as to preclude the possibility of the outcome of the operation being influenced by disinformation put out by the enemy.

On the subject of the discreteness of the information relating to the object being forecast, it is necessary to say a few words about the length of the intervals between observations of this object. In some cases these intervals are set for us against our will and desire. Thus, for example, specialists in military history avail themselves of data on past wars and armed conflicts "prepared for them by history." In some cases discreteness may be selected on the basis of considerations of the accuracy of presentation of the process being forecast as given by discrete information. Thus, V. A. Kotel'nikov's well-known theorem permits a strictly scientific selection of the interval between observations of a continuous process under conditions when there is no loss of information about this process [28]. In certain conditions involving conflicting requirements the optimal interval between observations can be found by the use of optimization. Specifically here, in coordinate axes (figure 5), where the length of the interval is plotted along the abscissa and a given "worth" of this interval along the ordinate, we construct curves of increasing and decreasing "worths" as they relate to an increase in the interval of observation. Their sum represents the total worth, the minimum value of which corresponds to the optimal (from the point of view of the total worth) interval between observations. A worth which increases with an increase in the observation interval implies the possibility of a loss of information about the process being forecast. A decreasing worth is characterized by a reduction of certain of the technical requirements with respect to the system when the interval between observations is increased. For example, the scanning speed rate of a surveillance radar antenna should be such

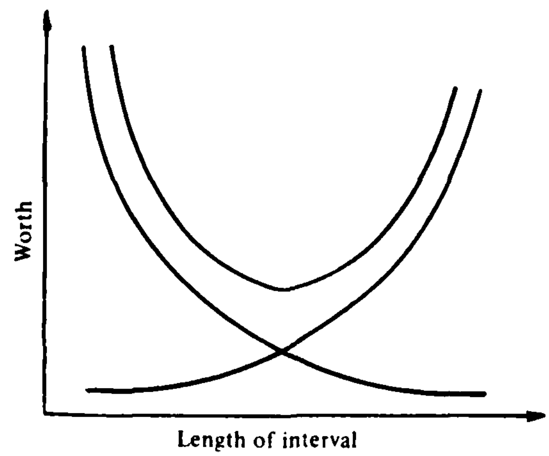

Figure 5. One of the Methods of Determining the Length of the Interval Between Observations.

that it does not miss a single target. In this example a decreasing worth with an increase in the interval between observations may characterize, for example, a reduction in the demands on the high-speed response and memory capacity of the computer which computes the characteristics of the process as new information is received. Thus, as this example shows, in some cases the selection of the observation interval presupposes the carrying out of independent research operations.

From the above discussion it can be concluded that even the first stage of the research process of forecasting—the collection and preparation of initial data—calls for great attention on the part of the investigator.

4. Requirements Which the Forecasting System Must Meet

In the preceding sections we have defined the concept "forecasting system," and considered its structure and parameters and the necessary information which serves as a basis for carrying out the research process of forecasting. In this section we shall consider the requirements placed on a forecasting system.

Obviously, the main requirement which a forecasting system must meet is that the forecast results (the forecast) should be accurate. For high-quality forecasts and forecasts of the "yes/no" type the concept of accuracy is unambiguously defined by whether or not a future phenomenon or process coincides qualitatively with what was assumed (forecast) beforehand. If, for example, a qualitative forecast of the possibility of armed conflict takes the form: "At a given interval of time in the future an armed conflict will/will not occur and will be of such and such a character (world, local, nuclear, nonnuclear, etc., etc.)," the degree of accuracy of such a forecast can be judged by whether or not the future situation corresponds with the forecast or not. It should be noted, however, that this example is not strictly correct, since no single forecasting system gives even a qualitative forecast in such a categorical form as "will/will not," "world/local," "nuclear/nonnuclear," but relates a particular forecast to the concept of the probability of a future event. Thus, for the sake of greater precision in the above example, we would have to formulate it as follows: "At a given interval of time in the future an armed conflict will/will not occur with probability P and will be of such and such a character (with probability Q, a world war; with probability R, a nonnuclear war, etc.)."

Thus, even in this example we can trace the relationship between qualitative and quantitative forecasts. However, such a simplification can be justified in the interests of defining the concept of the accuracy of a

qualitative forecast. For example, if we forecast (let us assume with probability $P = 0.95$) that at a given interval of time in the future an armed conflict will occur, and it does not occur, the forecast should be considered inaccurate (despite the fact that we had "in reserve" a 0.05 probability that it would not occur).

It should be noted that such an estimate of the accuracy of a forecast, although correct, would not satisfy an investigator, since we cannot await the moment of fulfillment of a forecast in order simply to state calmly that the forecast was or was not corroborated. Thus, an a priori assessment of the accuracy of a forecast is necessary, since it gives us reason to be confident about the actions undertaken on the basis of information provided by a particular forecast of operations. We shall discuss the methods of a priori assessment of the accuracy of forecasts when we consider specific methods of forecasting.

Before moving on to the accuracy requirement of a quantitative forecast we shall quote an example of a qualitative forecast about the inevitability of a world war made by Engels: ". . . For Prussia-Germany no other war but a world war is now possible. And this would be a world war of unprecedented scale and intensity. Between eight and ten million soldiers will throttle each other and in doing so strip the whole of Europe cleaner than any plague of locusts ever has."[2]

It is convenient to define the quality of a quantitative forecast in terms of the characteristics of its accuracy. Where uncertainties attend the process being forecast, no forecast can ever describe a future situation with absolute accuracy. Indeed, a forecast of the type "The military budget of country *X* in 1985 will be 1,345,247,615 dollars and 25 cents" cannot be taken seriously. In actual fact it seems most unlikely that a point forecast made by any given method would coincide precisely with the actual military budget of country *X* in 1985 (the figures for which cannot be obtained before 1985). Here it is appropriate to quote Engels on this point: "If our premises are right and if we correctly apply the laws of reasoning to them, the result must accord with reality. . . . But, unfortunately, this almost never happens, or if it does, it is in extremely simple operations."[3]

We can conclude from the above, therefore, that it is completely wrong to require that a forecasting system be capable of producing a point forecast that corresponds precisely with the future value of the process or phenomenon being forecast, and then to judge the accuracy or inaccuracy of the forecast on the basis of this correspondence. Obviously, in this respect all qualitative forecasts will be inaccurate (or, strictly speaking, almost all, since, after all, correspondence is theoret-

ically possible). However, although it is wrong to require that a point forecast be exact, it is entirely reasonable to require that a forecasting system which employs scientific methods of research and computation should be capable of ensuring that the future value of the process being forecast falls (with a given probability) within a certain range, determined during forecasting, i.e., within a range determined by the interval forecast. Returning to the example of the military budget of country *X*, we can say that a forecast of the type "The military budget of country *X* in 1985 will, with probability *P*, be 1,300,000,000 ± 50,000,000 dollars" now differs substantially in realistic terms from the forecast quoted above. Thus, a forecast which correctly determines the range of the future value of the process being forecast can be considered accurate. However, the given condition of accuracy, although necessary, is not sufficient, since the practical value of the forecast depends largely on the magnitude of the range into which the future value of the process falls with a predetermined degree of probability. And in this sense the **most accurate,** a priori, can be considered the forecasting system that ensures the smallest value of this magnitude. Actually, what practical value is there in a forecast such as this, for example: "The military budget of a country *X* in 1985 will, with a probability of 1, be 0 to *K* dollars," where *K* is the maximum possible state budget of this country in the indicated year?

Thus, the term accurate will be applied to a **quantitative forecast** which gives some finite minimum value of the range, meeting practical requirements, into which the future value of the process being forecast falls with a given degree of probability.

We shall apply the term **accurate qualitative forecast** to a forecast that indicates a qualitative aspect of a future event or phenomenon with the required degree of probability. As follows from the foregoing discussion, since the accuracy requirement of a forecast is expressed directly in terms of its accuracy and probability characteristics, we shall in the future, when evaluating and comparing different forecasts, use their accuracy and probability characteristics, since these yield readily to formalization and can be analyzed by mathematical methods.

Thus, the requirement of forecast accuracy is fundamental to the forecasting system.

The next important requirement which a forecasting system must meet is the capacity to react rapidly to changes in the object of the forecast. When current observations of the object of the forecast do not accord with our expectations, i.e., when forecasting errors occur, there could be various reasons. One of these reasons, as we have repeatedly emphasized, is the effect of the uncertainties that accompany the devel-

opment of the process being forecast. However, when receiving fresh information about the object being forecast, we cannot always be sure that forecasting errors are due to uncertainties. We should point out here that by uncertainties should be understood processes and phenomena which in each specific case, for various reasons, cannot be predicted or forecast. The "effect of uncertainties" on the forecasting process will be determined mathematically when we consider the question of mathematical methods of forecasting. A situation may arise in which forecasting errors are the consequence of changes in the object itself (in the very essence of the process) which have not yet been taken into account in the model. And, whereas in the previous case the task of the forecasting system is the filtration, the sifting out, of uncertainties, in the present case the forecasting system must with the maximum required speed recognize these changes in the object of the forecast and reflect them in future forecasts. Earlier we spoke about the indications from which it is possible to recognize and forecast enemy actions (particularly preparations for an offensive). However, the means and methods of armed conflict are continually changing. Many traditional operations which the enemy conducted in the front line zone before launching an offensive in the last war are now obsolete. However, even in a new situation, an enemy must take some measures (even though different from those which would have been taken in the past) which would make it possible to recognize the main elements of his plan and correctly construct a new model of his behavior.

It is not difficult to see that the requirement for flexible reaction by the forecasting system to changes in the object of forecasting, despite its independence, is, in the long run, linked to the requirement for forecast accuracy.

Finally, in the most general case a change may take place in the object of the forecast concurrently with the effect of uncertainties. The enemy changes his plan of conducting combat operations, achieving this by taking the necessary steps, regrouping, etc., and at the same time camouflaging them with dummy maneuvers and other disinformation. This greatly complicates the task of the commander and his staff, since it is necessary to select from among all the indications (including those specifically "offered" by the enemy) only those which relate to the plan being prepared by the enemy and reject all those which camouflage it. A technical problem of a similar nature might be the forecasting of a useful signal with simultaneous interference filtering.

The above-mentioned requirement for rapidity of reaction of the forecasting system to changes in the object of the forecast is extremely important, since in any processes of development the alternation of the evolutionary and revolutionary spheres is natural. Thus, a forecasting

system should reveal in good time a transition from one sphere to the other in order to provide for the main task—the production of an accurate forecast.

The above requirements are shared by all forecasting systems. However, in a number of specific cases the forecasting system may have to meet certain other requirements associated with the specific nature of each concrete case. Thus, in problems relating to the control and guidance of ballistic missiles, the requirement for high speed is of great importance. High-speed computers are needed for the solution of these problems. Where severe economic limitations are a consideration, the requirement to limit the cost of production of a forecasting process may be a major factor. In some cases the equipment which is used to automate the forecasting process may have to satisfy requirements for simplicity, lightness, compactness, etc.

5. Criteria in Forecasting

As is evident from the block diagram of a forecasting system and the sequence of computation and research operations in forecasting, the selection and substantiation of the type of model of the object being forecast is followed by the stage in which an estimate is made of some of its unknown parameters.

If, in analyzing available information, a model of an offensive operation is taken as a model of the enemy's actions, then in order to be able to reflect it effectively the commander will need to know such parameters as the time at which the operation will start, the sector of the main thrust, the quantities of forces and resources involved, etc. If an aerial target is engaged on the assumption that it is moving at a uniform speed and in a straight line in the impact zone, the unknown parameters of the model are the magnitude and sense of the target's velocity vector and the coordinates of its entry into the indicated zone.

Obviously, the unknown parameters of a model that are to be determined can be obtained by various means, depending on the criterion selected to characterize the best values of the parameters. If, for example, rapidity of determining unknown parameters is selected as a criterion, i.e., if we assume that the best values of the unknown parameters of the model are those which are determined most rapidly, it is not difficult to imagine the results of such forecasting if we remember the well-known everyday proverb: "The more haste, the less speed." Of course, in the majority of cases, the main criterion for estimating the unknown parameters of a model cannot be the time it takes to determine them. However, this time is a limitation and in a number of cases is very rigid with respect

to the process of estimating parameters. Actually, it is quite inadmissible to recognize, reconnoiter, and estimate the time of attack, the number of forces, etc., of a parameter represented by an enemy preparing to attack, right up to the moment he delivers his main thrust, while the idea of a commander taking a little piece of paper and carefully calculating the coordinates of a ballistic missile heading towards its target is too ridiculous for words.

Reasoning from the main requirement for any forecasting system—accuracy of forecast—it can be concluded that the main requirement with respect to the quality of an estimate of the unknown parameters of a model is the accuracy with which they are determined. Thus, we shall assume that the best parameters of the model are those which ensure the most accurate forecast, while meeting the set limitations with respect to the time of their estimation. Let us assume in further discussions that the type of model of the object being forecast has been correctly selected (corresponds to reality), since even the most accurate calculations of the parameters of an incorrect model will result in an inaccurate forecast. Let us see how necessary it is to estimate unknown parameters of a model in such a way that the forecast error is minimal. In those cases where the forecasting system is the human brain it is extremely difficult to formalize the forecasting processes in a general form. We can say that in heuristic forecasting man is guided by such concepts as, for example, "usefulness" and "penalty," intuitively using them when he forecasts the quantitative and qualitative aspects of a future event.

In cases where the forecasting system involves some type of mathematical system, the criterion of the best estimate can be described in mathematical language. One important method of estimation is the method (criterion) of maximum likelihood. Since a future situation is uncertain, the criterion of maximum likelihood is widely used in mathematical forecasting, because it is a probabilistic criterion. When this method is used, it is assumed that the best forecast will be the one based on a model whose parameters in the zone of observation are determined by the indicated method.

The basic idea of this method consists in determining the so-called likelihood function, usually the conditional probability density $p\,(y|a_1, a_2, \ldots, a_n)$, which links the parameters to be estimated $\bar{a} = (a_1, a_2, \ldots, a_n)$ with the random observations (measurements) of value y of the process to be forecast. After determining the likelihood function, the latter is maximized with respect to $\bar{a}$.

Let us assume that we know the form of probability density:

$$p\,(y) = p\,(y, \bar{a}), \qquad (1)$$

where $\bar{a} = (a_1, a_2, \ldots, a_n)$ are unknown parameters of the model of the object being forecast, which are to be determined. On this assumption, the problem of estimation can be formulated as follows: **given** a series of independent observations (measurements) of value y to be forecast in observation zone $y_1, y_2, y_3, \ldots, y_m$, we are **required** to find the best estimate of the model parameters $\bar{a}$ based on these observations (measurements), i.e., we are required to determine for what values of the model parameters the aggregate of observations (measurements) $y_1, y_2, y_3, \ldots, y_m$ is most likely to appear.

To solve the above problem we shall define the likelihood function as the probability density (1):

$$L(y, \bar{a}) = p(y, \bar{a}). \tag{2}$$

The required estimates $\hat{a} = (\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_n)$ of the actual parameters $\bar{a}$ of the model are found from the conditions:

$$\left.\begin{array}{l} \dfrac{\partial L}{\partial \hat{a}} = 0; \\ \dfrac{\partial^2 L}{\partial \hat{a}^2} < 0. \end{array}\right\} \tag{3}$$

The first of the conditions in (3), as we can readily appreciate, is that of the extremum of function L, and the second is the condition that this extremum is the maximum.

Let us consider the following model of process y to be forecast:

$$y = Aa + \eta, \tag{4}$$

where

y = m measurements $y_1, y_2, \ldots, y_m$ of the magnitude of the process to be forecast;

$\bar{a}$ = the unknown n parameters $a_1, a_2, \ldots, a_n$ of the model that are to be determined;

η = $(\eta_1, \eta_2, \ldots, \eta_m)$ random nonforecastable interference (uncertainty) which is independent of $\bar{a}$;

A = a certain known matrix of dimensions $(m \times n)$, which characterizes the influence of parameters $\bar{a}$ on the process y in question, so element A_{ji} ($j = 1, 2, \ldots, m$, $i = 1, 2, \ldots, n$) of matrix A characterizes the influence of parameter a_i on measurement y_j.

Model (4) assumes that distortions (interference) are "superimposed" (summed) on the process being forecast. The action of interference of this type is called additive action, and the interference itself, additive interference. It should be noted that processes described by model (4) are very widespread in practice. In fact, if, for example, it is assumed that y denotes the results of radar measurement of the actual parameters of a target $y_g = A\bar{a}$, then η can only be various types of radio interference (artificial and natural) picked up by the radar set.

Let us assume that condition $m>n$ is fulfilled, i.e., that the number of equations is not less than the number of parameters a_i to be determined.

We rewrite the expression for the likelihood function in the form

$$L(\bar{a}) = p(y \mid \bar{a}) = \frac{p(y, \bar{a})}{p(\bar{a})} = \frac{p(\bar{a}, \eta)}{p(\bar{a})} =$$
$$= \frac{p(\bar{a})\, p(\eta)}{p(\bar{a})} = p(\eta) = p(y - A\bar{a}). \qquad (5)$$

To determine the optimal estimation $\hat{a}$ in the sense of the method of maximum likelihood, we write the first condition of (3) above in the form

$$\frac{\partial L}{\partial \hat{a}} = \frac{\partial [p(y - A\hat{a})]}{\partial \hat{a}} = 0. \qquad (6)$$

If η is normally distributed interference with an expected value of zero, it can be shown that the maximization of $L(\bar{a})$ is equivalent to the minimization of a sum of the type

$$\sum_{j=1}^{m} [y_j - f(\hat{a}, x_j)]^2 = \min, \qquad (7)$$

where $f(\hat{a}, x_j)$ is the value of process y at the jth point to be estimated by the deterministic part of the model.

Expression (7) characterizes the method of least squares, which has been widely used in the solution of forecasting problems. Thus, the least squares method is a particular instance of the maximum likelihood method, where the interference is an additive process normally distributed. Readers who would like to have more detailed information about this method and its fields of application are referred to works such as Yu. V. Linnik's book [32].

The least squares method enables us to find estimates of $\hat{a}$ such that the sum of the squares of the deviations of the values of the process to be defined by the deterministic part of the model from available observations (measurements) will be the least for the given statistics. It is

evident from expression (7) that all the differences (for any j) are assumed to have the same weight, i.e., we regard measurements made at any moment of time as being equally reliable. However, in solving certain forecasting problems it is expedient to give these differences a dissimilar weight, whereupon the weight should, as a rule, be reduced with a decrease in the number of j's, i.e., earlier (older) observations are given less weight (we have less confidence in them) than later (newer) ones.

In this case the criterion for (7) will take the form

$$\sum_{j=1}^{m} w_j^2 [y_j - f(\hat{a}, x_j)]^2 = \min, \qquad (8)$$

where w_j^2 is the weight of the jth square of the difference, which varies from observation to observation according to a certain law given by us.

In considering mathematical methods of forecasting in subsequent chapters we shall examine the application of criterion (8), which by analogy with the least squares method can be called the "weighted" least squares method. In forecasting parameters of stationary random processes we can use the criterion of the minimum variance of difference between the magnitude of the forecast made at moment of time t with a lead interval Δt and a future value of the stationary random process at moment of time $t + \Delta t$. The criterion for estimating unknown parameters of a model in forecasting nonstationary random processes is analogous in meaning.

In addition to the criteria considered above, others can be used in some cases, for example, the criterion of the minimum of the maximum deviation of the values of the process given by the deterministic part of the model from available observations (measurements), etc. The choice of a particular criterion for estimating the unknown parameters of a model depends on the type of the object of the forecast and the problems which the forecasting system is expected to solve, and requires special consideration in each specific case.

We shall give two examples of the practical use of the criterion of the least squares method.

Example 2. For the preparation of an offensive operation it is necessary to know (forecast) the future rate of advance of the combat formations.

The following rates of offensive advance are based on experience gained from four previous operations: V_1 = 30 km per day, V_2 = 40 km per day, V_3 = 50 km per day, V_4 = 60 km per day.

What rate should be accepted for the preparation of a future operation? If we decide to solve this problem mathematically, the solution may be as follows.

Take as the model of the rate of advance, a model of constant speed

$$f(\hat{a}, x) = \hat{V}.$$

According to the criterion of the minimum sum of the squares, we have:

$$I = \sum_{j=1}^{4} (V_j - \hat{V})^2 = \min;$$

$$\frac{\partial I}{\partial \hat{V}} = -2 \sum_{j=1}^{4} (V_j - \hat{V}) = 0,$$

whence

$$\hat{V} = \frac{1}{4} \sum_{j=1}^{4} V_j = \frac{1}{4} (30 + 40 + 50 + 60) = 45 \text{ km per day}.$$

i.e., the average of the observations (the average of the four rates) gives the best estimate of the future rate of advance in terms of the least squares method.

Example 3. The annual expenses for operating a motor vehicle, as a function of the period of use, are given in the following table:

Year (t_j)	1st	2nd	3rd	4th
C_j (rubles)	490	1,050	1,600	1,950

It is necessary to forecast operating expenses for the fifth and sixth years in order to reach a decision on the advisability of replacing the motor vehicle.

The figures in the table show that the relationship between expenses and time is close to linear.

We shall use a linear model of the form

$$C = a_1 + a_2 t + \gamma_t.$$

The problem amounts to estimating the unknown parameters, a_1 and a_2, of the model. Using the criterion of the minimum sum of the squares, we have

$$I = \sum_{j=1}^{4} [C_j - \hat{a}_1 - \hat{a}_2 t_j]^2 = \min,$$

whence:

$$\left.\begin{aligned} \frac{\partial I}{\partial \hat{a}_1} &= -2 \sum_{j=1}^{4} (C_j - \hat{a}_1 - \hat{a}_2 t_j)^2 = 0; \\ \frac{\partial I}{\partial \hat{a}_2} &= -2 \sum_{j=1}^{4} (C_j - \hat{a}_1 - \hat{a}_2 t_j) t_j = 0, \end{aligned}\right\}$$

whence:

$$\left.\begin{aligned} 4\hat{a}_1 + \hat{a}_2 \sum_{j=1}^{4} t_j &= \sum_{j=1}^{4} C_j, \\ \sum_{j=1}^{4} t_j \hat{a}_1 + \hat{a}_2 \sum_{j=1}^{4} t_j^2 &= \sum_{j=1}^{4} C_j t_j, \end{aligned}\right\}$$

or

$$\left.\begin{aligned} 4\hat{a}_1 + 10\hat{a}_2 &= 5090; \\ 10\hat{a}_1 + 30\hat{a}_2 &= 15190, \end{aligned}\right\}$$

whence: $\hat{a}_1 = 40$ rubles, $\hat{a}_2 = 493$ rubles per annum. Thus the deterministic part of the model has the form

$$C = 40 + 493t \text{ (rubles)}.$$

Substituting in it $t = 5$ and $t = 6$, we obtain the forecast values for the operating expenses for the fifth and sixth years, respectively: $\hat{C}_5 = 2{,}505$ rubles, $\hat{C}_6 = 2{,}998$ rubles.

The resulting point forecasts, as already indicated, are not sufficient for solving the given problem, and in this example they serve simply as an illustration of the use of the criterion of the least squares method.

It cannot be said that the above examples involved any great calculation difficulties.

However, in practice, problems are encountered in which the number of observation (measurement) points is reckoned in tens and even hundreds, while the models of the processes are considerably more complex than constant and linear models. In these cases, even if the problem has an analytical solution (when the models are linear with respect to the unknown sought parameters), the calculation difficulties increase so much that computers are required for the successful and timely solution of forecasting problems. Examples of the use of computers will be given when we come to the solution of some forecasting problems in the chapters on mathematical methods of forecasting.

We have considered certain mathematical criteria used in forecasting which are clear, precise, and self-evident by virtue of the simplicity, clarity, and precision of formulation of the problem.

However, investigators in the military field are frequently confronted with such complex and massive forecasting problems that the mere selection of a criterion for the best estimate of a model's parameters becomes a complicated task in itself.

Let us take, for example, the problem of forecasting a rear services support system. We ask ourselves the question: what kind of criterion should we select for determining the best support system? On the one hand, all the increasing complexity and proliferation of arms and military equipment, troop mechanization, etc., call for an increase in the volume of work associated with rear services support. On the other hand, the need to increase troop mobility and maneuverability calls for a reduction in the numerical strength and facilities of rear services support. If we consider that the criterion should take into account the possibility of estimating not only the quantitative, but also the qualitative composition of the rear services and rear services support units, the full extent of the complexity of the choice of such a criterion becomes apparent.

It is of interest to note Engels' imaginative solution to the problem of the optimal criterion for selecting rear services support facilities based on camp stores in the work *Possibilities and Prospects of the War of the Holy Alliance Against France in 1852*: "Modern armies, unlike the small armies of the period of the Seven Years' War, cannot march back and forth across the land for months within some 20 miles. They are unable to bring with them all the necessary provisions in field stores. . . . Field supplies fulfill their purpose if they do not contain more than may be needed in unforeseen cases."[4]

If we follow Engels' recommendations in working out a criterion for determining the composition of the forces and resources for the support of a modern army's rear services, we can say that it should be based on a scientifically substantiated time of autonomous combat operations of a specified degree of intensity by the units and formations involved. Thus, although the selection of a criterion for estimating unknown parameters of a model is the last stage of research operations just prior to carrying out calculations for a forecast, it is in some cases far from being the last in significance, complexity, and volume of work involved.

NOTES

1. In heuristic forecasting the last four processes take place subconsciously in the brain.
2. Marx, Engels, XXI, 361.
3. Marx, Engels, XX, 629.
4. Marx, Engels, VII, 506.

Chapter 3. Special Features of Forecasting in Military Affairs

1. General Observations

We have said that by virtue of certain special features military forecasting is a completely independent branch of the overall process of scientific forecasting. It is the complexity and specific character of armed conflict that have given rise to the special features of military forecasting. The complexity of military forecasting is particularly marked under present-day conditions. At the same time it is precisely under present-day conditions that military forecasting is becoming so important.

Let us enumerate briefly the main features of military forecasting which stem from its specific character and scale.

First and foremost we should note **the large number and diverse character of the uncertainties** which accompany processes that are forecast in the military field. There are a good many reasons for this.

Firstly, the uncertainties inherent in nonmilitary processes and phenomena apply in full measure to military affairs. For example, the uncertainties involved in weather forecasting processes apply equally to all forecasting systems, military and nonmilitary.

Another characteristic of military affairs in many cases is the incompleteness of available information owing to the particular conditions governing the collection and preparation of this information. This can be attributed to, for example, the difficulty of penetrating enemy territory for the purpose of obtaining the necessary intelligence and for verifying already available data, as a result of which it is, as a rule, impossible to obtain full and accurate information about the enemy. Finally, each of the opposing sides tries by every available means to hide its true goals, developments, and ideas. On the other hand, each of the opposing sides tries to mislead the enemy by various forms of disinformation. In the

latter case the aim is to make the enemy construct an incorrect forecasting model and thus to make mistakes. This first characteristic feature of military forecasting, already a complex process, makes it even more complex and difficult and imposes additional demands on the respective agencies and individuals.

In many cases the level of uncertainties which accompany the process being forecast can be reduced by means of various tests and experiments. In military affairs an experiment is either altogether impossible or exceptionally difficult and limited. For example, it is obviously impossible to carry out an experiment in conducting combat operations in peacetime. To obtain needed information in wartime it is sometimes necessary to carry out reconnaissance in force, to capture "a tongue," etc. It is not difficult to see the difference between such methods of obtaining information and a scientist's laboratory experiments and tests (frequently very complicated and laborious). Thus, **the complexity (and in some cases the impossibility) of an experiment** is the second special feature of military forecasting.

Obviously, this characteristic of military forecasting exerts a direct influence on the first one, since the pertinence (or impossibility) of experimentation is expressed in the retention of the associated uncertainties which hamper the forecasting process.

The next special characteristic of forecasting in military affairs is **the extreme complexity of a number of processes that are forecast and the large scale of military forecasting.**

For example, military-strategic forecasting involving questions of armed conflict as a whole must also take into consideration the results of operational-tactical forecasting and other divisions of military forecasting. In turn, the results of military-strategic forecasting have a direct effect on the process of operational-tactical forecasting and other divisions of military forecasting. An example of military-strategic forecasting is seen in the tenets of military doctrine on the special features of nuclear war, the means and methods of conducting armed conflict, etc. The results of operational-tactical forecasting are exemplified in the requirements of the pertinent regulations and instructions, which represent generalized models of the use of particular means and forms of combat operations in war. These models are not a set of stereotyped patterns. They are continually being refined and modified as military science, equipment, and weapons develop. But even the most sophisticated models, being generalized, cannot provide exhaustive recommendations in every concrete case, and the task of the commander in forecasting a concrete combat situation is to use his knowledge of the appropriate regulations

and instructions as a guide and to apply them in the manner demanded by the situation which is actually taking shape, displaying initiative and creativity. General of the Army P. N. Lashchenko, writing on this subject in his memoirs, says: "Every battle was unlike any other that preceded it in character, correlation of forces and sides, and the situation in which it was fought. This required all commanders to have a profound knowledge of military science, operational efficiency and initiative, boldness and resolution, and the ability to use every favorable factor of the situation in the interests of achieving victory over the enemy" [30].

It should be noted in considering the scope and enormous scale of military forecasting that military science, unlike a number of other sciences (such as, for example, oceanography, meteorology, geology, etc.) extends to all the spheres of space accessible to us—the earth's surface, the seas and oceans, the atmosphere and outer space.

As regards the feature of military forecasting arising out of the enormous scope and scale of the processes in military affairs, we cannot pass on without referring to **the close relationship between military forecasting and other divisions of scientific forecasting.** As we have already noted in discussing the main divisions of military forecasting, the latter is inconceivable unless it is related to the forecasting of political situations, the development of science, technology, economics, and social forecasting, etc. This feature of military forecasting increases and emphasizes the great complexity and enormous scale of military forecasting.

The existence of this relationship and the effect of military forecasting on other branches of scientific forecasting impose additional demands on its accuracy, since the results of military forecasting inevitably affect the other fields of forecasting referred to.

The last two features of military forecasting considered above are the direct cause of the next characteristic, which is related to the **high cost of its errors.** However, this characteristic is determined not only by the enormous scale and close relationship of military forecasting to other branches of scientific forecasting, but also by a number of specific characteristics of the concrete military processes being forecast. Thus, for example, the advent of thermonuclear weapons gave rise to the possibility of thermonuclear war. Thermonuclear war, if we do not succeed in preventing it, will differ in its consequences from all previous wars. It will bring enormous destruction and loss of human life. According to the forecast of Herman Kahn, if 80 million Americans were killed in such a war, it would require 50 years for the American economy to recover, and if 160 million Americans were killed, the recovery period would increase to 100 years [71].

On the other hand, accurate forecasting puts great benefits within our reach, particularly in the economic field. According to a report issued by the RAND Corporation, the saving in funds for the U.S. Department of Defense, thanks to a "planning-programming-budgeting" system based on forecasting, amounted to $14 billion during the period 1962–1965. Experts of the RAND Corporation reckon that with the aid of day-to-day recording of data contained in forecasts, at least $6 billion a year could be saved for the Department of Defense beginning in 1969 [56].

The high cost of errors in military forecasting is greatly increased by the fact that military problems have, as a rule, to be solved in very limited periods of time. **The limited time** allocated for the implementation of the forecasting process is the next distinguishing feature of military forecasting. At this point it would be appropriate to quote the following remark made by Napoleon: "It may be that in future I may lose a battle, but I shall never lose a minute" [14]. Whereas the study and forecasting of the position of some heavenly body, for example, is not confined within rigid limits, since the value of the time taken to produce a forecast is not high in this case, the consequences of a loss of time in the detection, forecasting, and solution of an aerial target interception problem are not difficult to imagine. If nuclear missile weapons are used, the timely discovery of the enemy's intentions concerning the time and targets of a nuclear strike is of great importance. The requirements for accuracy and speed in the production of a forecast are in conflict with each other. However, the unavoidable necessity of fulfilling these requirements makes the process of military forecasting more crucial still. Finally, an extremely important feature of military forecasting is the **exceptional role of the military leader** in the process of forecasting and decisionmaking. This is due primarily to the presence of the above-mentioned first characteristic feature of military forecasting, associated with the presence of a large number of natural and artificial uncertainties. Under these conditions very effective use can be made of the capacity of the human brain to operate with vaguely formed concepts. This characteristic is also a consequence of the circumstance that war envisages the participation of a large number of people both directly in the process of combat operations, and in the sphere of supporting these operations.

Thus, as the foregoing shows, military forecasting possesses a great many important interrelated and interdependent characteristics which mark it out as an independent division of scientific forecasting. We shall dwell in somewhat more detail on some of the features of military forecasting referred to above.

2. Information in Military Forecasting

One of the principal features of military forecasting, as already indicated, is that it involves a large number of uncertainties which in many

cases are of an artificial nature. We have already referred to the fact that a distinguishing feature of military forecasting is its large scale. It is concerned with forecasting not only in strategic, operational-tactical, and economic problems, but also in technical problems.

Problems associated with observations, the collection and processing of information in the natural sciences—which include the majority of military-technical problems—are attended by uncertainties, which are, as a rule, of a natural character. And although the collection and analysis in many cases may be attended by considerable difficulties (for example, of a technical nature), in these cases the information nevertheless objectively characterizes the process being forecast. Actually, as Albert Einstein aptly remarked: "The Lord God is subtle but he is not malicious."[1] This is the way it is when nature appears as our "enemy" in the solution of some forecasting problem or other.

It is another matter when the processes being forecast involve consideration of a competing or opposing side represented by various groups of people pursuing their individual and sometimes diametrically opposed aims. This happens in forecasting associated with economic (in the calculation of enemy resources), strategic, and operational-tactical problems.

Characteristic data for sources of uncertainties and for accuracy of economic-statistical observations are given in O. Morgenstern's book [36]. The author points to intentional falsification of information in economics, which in simple or well-studied systems (for example, mechanical systems) is difficult and often impossible. Morgenstern indicates two principal distinctive sources of falsification in economics.

Firstly, the observer may intentionally hide information or falsify his observations so that they agree with his hypothesis or political objectives. This happens in historical treatises and even in the natural sciences—in exceptional cases and considerably more frequently when economic and social statistics are used or abused by unscrupulous individuals or organizations.

Secondly, the object of observation may consciously lie to the one gathering the information.

This kind of situation comes up in processes which characterize an armed struggle between two opposing sides, in military-strategic and operational-tactical forecasting. These are the tasks which face the general in war, in the words of Sun Tzu:

> War is the way of deception. Therefore, if you are able to do something, act towards the enemy as though you are unable to do it; if you are able to

> profit by anything, make him think that you cannot; even though you are close to him, make him think that you are far away; if you are far from him, make him believe that you are near; lure him with the chance for a gain; throw him into confusion and take him; if he is ready for you, be ready for him; if he is strong, avoid him; having aroused his anger, confuse him; having adopted a meek appearance, arouse in him a sense of self-importance; if his strength is fresh, tire him out; if there is harmony among his forces, sow discord; attack him when he is unprepared; advance when he least expects you to.*

During the Great Patriotic War the Soviet Army carried out a number of large-scale and successful operations aimed at disinforming the enemy.

For example, in the summer of 1944 the German Command had surmised that an offensive by Soviet forces in Belorussia was a possibility, but was unable to determine the sector of the main thrust. In order to mislead the enemy, the troops engaged daily in defensive work, constructing barbed-wire entanglements in front of the forward edge and mining the terrain. Personnel were issued instructions and memoranda on the organization of defense. Troop movements took place only at night, while during the day their camouflage was checked from the air by responsible staff officers of the front, as well as by officers of the General Staff. In order to hold the enemy's operational reserves on other sectors of the Soviet-German front, the 3rd Ukrainian Front was instructed to simulate a large-scale concentration of forces, ostensibly preparing for an offensive against Kishinev. This mission was carried out successfully, though it entailed a considerable expenditure of forces and resources. Simulating the concentration of an army consisting of eight rifle and two artillery divisions, a tank corps, and army rear services was achieved at a cost of approximately 200,000 man-days and a vast quantity of materials over a period of one and a half months. As a result of these measures the enemy failed to discover the real purpose of these activities and not only did he not send his reserves into Belorussia, he even reinforced the first echelon troops facing the 3rd Ukrainian Front [46].

The experience of World War II and other wars shows that the success of any operation is inconceivable without camouflaging both the military objectives themselves and the operations of the troops. Camouflage under present-day conditions has become an art, based on the achievements of modern military science and technology. In peacetime,

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*[See B. H. Liddell Hart, *Strategy: The Indirect Approach* (New York: Praeger, 1954), pp. 13, 14. This is the source to which the Soviet edition refers, but the reader will note that this is an extremely free translation. It would appear that the Russian translator intended to convey the basic philosophy of Sun Tzu, but he has achieved it by paraphrases and by indicating statements that are nowhere present in the English language edition—U.S. Ed.]

camouflaging means and methods are being continually improved. One may assign camouflage to three conventional categories: tactical, operational, and strategic. The purpose of tactical camouflage is to increase the level of uncertainty for the enemy by utilizing the time of day and geographical and meteorological conditions, by using different means and devices for camouflaging individual installations and subunits, and by simulation involving dummy installations and dummy tactical operations. The aims of operational camouflaging are achieved by maintaining the secrecy of preparations for an operation, by setting up dummy defensive installations, etc. It is not difficult to see that the effect of operational camouflaging can be achieved only if tactical camouflage discipline is observed, while failure to observe operational camouflage discipline considerably reduces the effect of tactical camouflaging. Strategic camouflaging is required to resolve similar problems, but at a higher level and on a larger scale. Thus it is evident that there is a close relationship between all the available forms of camouflaging. The success of camouflaging under present-day conditions is determined largely by the availability of modern technical facilities (communications security, blackout resources, thermal camouflage resources, etc.). However, the improvement of camouflage means and methods is accompanied by improvements in intelligence means and methods, which, on the one hand, facilitates the task of reducing the uncertainties involved in forecasting enemy actions and, on the other hand, complicates the task of camouflaging one's own objectives and intentions.

Thus, on the one hand, the multiplicity and specific nature of the uncertainties which accompany processes and phenomena in military affairs make military forecasting extremely difficult and complex and, on the other hand, make it more necessary and important, if one is to give due regard to one of the above-mentioned characteristics of military forecasting—the high cost of its errors.

One way of overcoming these difficulties is to carry out a detailed study of the experience of past wars and all the attendant phenomena and processes. Without this it would be impossible to forecast trends in the development of military science or the course and outcome of a war with the necessary degree of accuracy. Emphasizing this thought, M. V. Frunze wrote that the study of the history of wars is not necessary of itself but in order to be able "to draw conclusions from it for tomorrow's use."[2]

The great attention that was paid to questions related to the collection, analysis, and processing of information in military affairs (military statistics) beginning in the first years of the formation of our state is attested to by the fact that in May 1921 the Revolutionary Military Council

of the Republic set up a department of military statistics. The purposes and aims of this department were defined in the Statute on State Military Statistics. Instructions were also given for the organization of the necessary statistics agencies at the center and in the military districts.

Military statistics deals with questions relating to the quantitative and qualitative indices of the military and economic potential of states, mobilization potential with respect to human resources, materiel support of the forces, etc. The collection and processing of military statistics enable us to formulate principles of military art, which are generalized models of the structure of combat operations in a future war. Even in ancient times people observed, on the basis of the accumulation and analysis of information about past wars, that in different wars similar situations occurred and that if a general in a particular situation made a decision which in the past had led to victory, he himself was victorious, and vice versa. It should be noted that military statistics, like mathematical statistics, provide sufficiently accurate information only if an ample quantity of historical material is processed. Liddell Hart's remarks in this respect are fully warranted: "With . . . a limited basis the continual changes in military means that have taken place in each war have created the danger that our outlook will be narrrow and our conclusions fallacious. . . . An intensive study of one campaign unless based on a good knowledge of the whole history of war is likely to lead to incorrect conclusions. But if a specific pattern is seen that is characteristic of different epochs and of diverse conditions, there is ground for including this pattern in a theory of war" [14].* The principles of military art have been built up on the basis of the generalization of military historical data. Some of them have retained their significance right up to our own time. Such is the famous "Epaminondas Principle," which consists in the irregular distribution of troops along the front and in depth for the purpose of concentrating forces in the main sector. This principle was first applied in 371 B.C. by the Theban general Epaminondas in the Battle of Leuctra.

In some cases a reduction in the influence of uncertainties can be achieved by the use of mathematical methods of computation and analysis.

We will conclude this section by citing two examples, given by the American military planning expert B. Radwick, † which characterize the

* [See Liddell Hart, *Strategy*, pp. 24, 25. This translation from the Russian does not accord exactly with the original English. The difference, however, is not so great as to warrant the repetition here of the author's original wording—U.S. Ed.]

† [See footnote, p. 4, this book—U.S. Ed.]

influence of different kinds of uncertainties involved in solving the problem of working out a scenario for a general nuclear war and the problem of determining the number of missiles needed to destroy a given number of targets [42].

Example 4. The creation of a general nuclear war scenario is one of the most difficult tasks and demands from its authors a high degree of imagination for describing future situations. The analyst obtains the information for putting together possible scenarios by considering various probable situations with a number of decisionmakers and with military experts. Each of those with whom he talks may have one or several opinions of his own concerning what will be the conditions to be dealt with in the period of time in question. This is a rather prevalent problem, and the systems analysis expert must also be prepared to meet it in a collection of information composed of the subjective evaluations of others. He copes with such uncertainties by careful study and clear presentation of all data and information that he elicits, including opposing opinions.

One of the possible scenarios may provide for consideration of an attack on the U.S. In such a scenario the U.S., having undergone the attack, must take measures to swiftly determine the damage inflicted, learn the source of this attack, and prepare for a retaliatory attack. Study of the possible scenarios shows that one can establish their logic by considering the following undetermined factors:

—the weapons of the enemy, number, type, characteristics;
—whether the enemy will strike first;
—available time for strategic warning;
—available time for tactical warning;
—targets hit in the first strike;
—forces used in the first strike;
—the extent of damage suffered by the U.S. and the nature of the retaliatory attack;
—the extent of damage suffered by the enemy and the nature of his retaliatory attack.

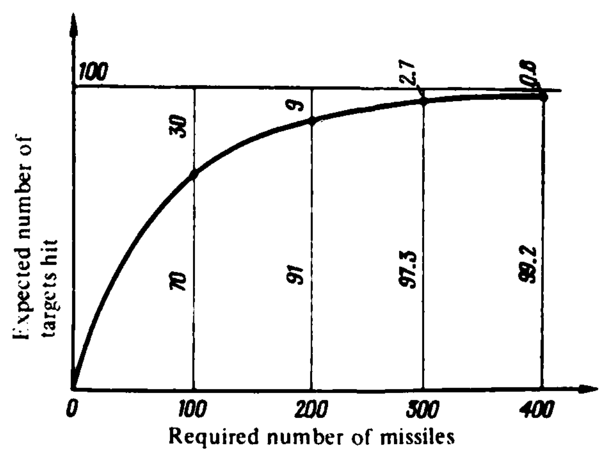

Figure 6. Number of Missiles Needed to Hit Various Numbers of Targets.

Example 5. To determine how many missiles are needed (and consequently, how much the corresponding missile system will cost) to hit 100 absolutely identical targets, if the probability of a hit with one missile on a given target is equal to 0.7.* Let us suppose that there is no way to determine if a given missile hit its target or not. Therefore, the only thing to do is to fire one or more missiles consecutively at each target. One may consider the problem solved if he finds the required number of missiles in each of the completely identical 100 salvos.

This problem may be solved in the following manner. In the event of a launch of 100 missiles consecutively at 100 targets (one missile per target) one can say with certainty that the number of targets struck will be somewhere between 0 and 100. For an absolute guarantee that all 100 targets are hit, it is necessary to launch an infinitely large number of missiles. The person who plans the development of the system must, in that case, choose more definite criteria for its effectiveness. One of these criteria may be the number of missiles necessary for the average number of hit targets (resulting from the large number of launches) to be no less than the assigned number. One may pose the question somewhat differently, i.e., "How many missiles are needed, for instance, to hit an average 95 targets out of 100?" Using this criterion, the entity planning the development may show that in the event that 100 missiles are launched at 100 targets (one per target), one can expect that 70 targets will be hit, and 30 targets will remain intact. This result is depicted in figure 6. With 200 missiles, 2 will be launched at each target. In this case 70 targets will be hit (on the average) twice with the probability rating of 0.7. Additionally, 21 of the remaining 30 targets will be hit and 9 will still be intact (0.7×30). Analogously, one can show that an investment of a third hundred missiles will result in hitting an additional 6.3 targets, and a fourth hundred will contribute to hitting less than two targets.

Consequently, to perform the mission assigned (in its second version) 300 missiles are needed.

3. Military Practice and Experiment in Military Affairs

Despite the a priori possibility of estimating the accuracy of a forecasting system in a number of cases, real data about its actual errors can only be obtained in performing the event being forecast, i.e., in practice. This circumstance is a consequence of the well-known Marxist-Leninist principle of practice and the criterion of truth. Practice is a means of verifying the authenticity of any knowledge, including knowledge about future phenomena and processes. In the course of people's practical

* We note that a probability rate of 0.7 (or any other) is arrived at on the basis of certain statistical data, which also contain some uncertainties—Author.

activities true knowledge gives the result that is anticipated, while incorrect, false knowledge gives a result that does not correspond to reality. The concept "correspondence" or "noncorrespondence" of given forecasts to reality is associated with the concept "accuracy of results of forecasting," defined in chapter 2.

A special feature of practice in military affairs is its differentiation into parts with quite different significance—armed conflict (war) and peacetime military practice. As we have already indicated, only in wartime is it possible to verify fully the truth of principles of military science, the truth of our ideas (forecasts) concerning the quantitative and qualitative aspects of processes and phenomena associated with armed conflict. However, military development continues, even in peacetime. In peacetime it is necessary to make responsible decisions concerning the elaboration of continually evolving principles of military science, and the development of prospective new types of arms and military equipment, having first determined these prospects, etc.

Obviously peacetime practice is not as comprehensive as wartime practice. It involves various exercises (troop, command and staff), the arming and logistical support of troops, the development and improvement of weapons and military equipment, weapons and equipment tests (factory, range, etc.), and special scientific research work and experiments.

Some of these measures permit forecasting and subsequent verification of its accuracy for conditions that are sufficiently close to wartime conditions. These include, for example, the forecasting of weapons and equipment specifications. At the same time, under peacetime conditions it is not feasible to verify new principles of military theory or to assess the effectiveness of the use of particular weapons in a combat situation. For example, a definitive assessment of an intercontinental ballistic missile system can only be made on the basis of the use of nuclear weapons, which is obviously out of the question. Therefore, in peacetime, investigators are forced to rely on the experience and practice of past wars. Of great importance in this connection is the question of the extent to which the experience of past wars and peacetime practice can serve as the basis for forecasting the processes and phenomena of a future war.

Thus, although the opportunities for practice in peacetime conditions have greatly improved, this is still no substitute for practice in wartime. This is a feature of modern military forecasting which places additional emphasis on the need for detailed analysis and scientifically based research when carrying out the forecasting process.

4. The Characteristics of Human Participation in Military Forecasting

Human creativity plays a very large part in the forecasting process. Heuristic forecasts are wholly the product of forecasting processes that take place in the human brain. Mathematical forecasting also includes man as a necessary element in the scientific preparation and analysis of data.

In military forecasting the human element plays a more important role by virtue of the fact that one of the principal processes in the military field—combat operations—involves the participation of a large number of people.

One of the conditions which influence the course and outcome of combat operations is the commander's decision. Making the concept concrete and determining the mode of operation, the commander's decision determines the program of combat activities and is the basis of troop command and control. The results of combat operations are largely determined by decisions made by the commander before and during combat operations. A correct decision made by the commander on the basis of an accurate forecast of the situation is an important condition of success. At the same time, military history is not lacking in examples of a general's erroneous subjective decision being the cause of the defeat of his forces. The actions of great military leaders have always been distinguished by their ability to penetrate deeply into all aspects of the existing situation. This is a prerequisite for accurate forecasting of such a situation in a future battle.

The commander's decision, which is a major factor in determining the results of combat operations, plays an increasingly important role in today's world of sophisticated weaponry. The reason for this is the increased cost of forecasting errors in modern warfare compared with what it was in the past.

Man's role in military forecasting also expands in connection with a whole variety of features related to his participation in this process. A most important place in the army is occupied by centralization, because without centralization the army could not be a unified organism, a coherent force. However, at the same time, centralization assumes creativity and initiative. In this connection Marshal of the Soviet Union M. N. Tukhachevskiy expressed the thought that "there is no point in centralizing command beyond what the troop commander can accomplish in practice. Overcentralization means virtual inaction, since the senior officer cannot put into effect what he wants to, while the junior officer is immobilized by centralization and must wait for instructions."[3]

A skillful combination of the strictest centralization with creativity and initiative is very important in cases where in the course of combat operations a previously contemplated plan has to be abandoned, i.e., in cases where the model undergoes changes during forecasting. Rigid centralization is required in cases where combat operations proceed according to plan (the model of the process does not change). Dialectical interaction of centralization and initiative was clearly evident during the course of the Great Patriotic War. Thus, for example, in the Jassy-Kishinev Operation, during the preparation to breach a static defense, the army commanders indicated to the first echelon rifle divisions operating in the sector of the main thrust the breakthrough sectors, the combat missions, the methods of carrying them out, and the structure of the combat formations, down to and including units and subunits [44]. During the pursuit of the enemy the opportunities for initiative were greatly increased. This, therefore, is one of the circumstances which determines the special role of an individual (the commander) in the process of military forecasting.

The special role of the commander is also called for by the requirement for exceptional operational efficiency in decisionmaking, which is a consequence of the feature of military forecasting associated with the trend toward reducing the time taken to produce forecasts in military affairs. Indeed, what other human activity makes such exacting requirements for rapidity of thought or for the time taken to forecast a situation and make a decision as that of the commander? Delays in decisionmaking deprive the troops of leadership and control when needed; delayed decisions can only state passively the flow of events, instead of giving them timely direction. The commander now has computer technology to assist him. This creates favorable opportunities for reducing the time taken to make decisions. Modern computers are capable of carrying out an enormous volume of calculations in very short periods of time. However, since the situation assessment and the readout of information for machine calculation are human functions, the time taken to make a decision still depends on rapidity of thought. Consequently, the use of modern computer equipment increases, rather than reduces, the need for rapidity of work on the part of the commander. This need is made even more acute by the fact that the commander must have a firm grasp of the essentials of a developing situation, since only then do the preconditions exist for the correct forecasting of combat operations. The commander's thinking, like all human thought, rests on past experience and knowledge. Rapidity of thought processes depends largely on depth of theoretical knowledge. In the use of knowledge and skill, the commander possesses a capacity which distinguishes him from, say, a mathematician or a physicist, who in solving their problems use principles and laws which, as a rule, reflect fixed relationships between numerical values and phenomena. The com-

mander in making a decision uses the regulations, instructions, and principles of military art, which are generalized models and thus not fixed patterns for any and all situations. For example, under some conditions a maneuver is useful and necessary; in others it may prove inexpedient, since it results in loss of time and inactivity of part of the forces for a certain period. Some principles and regulations are in conflict. Thus, in a sense, the principle of the concentration of forces conflicts with the principle of achieving surprise, while the need to deliver an initial powerful strike conflicts with the need to have strong reserves for building up efforts in the course of the battle. In order to resolve such contradictions the commander must reinterpret the textbook theoretical principles as they apply to the conditions of the actual situation. Thus, another characteristic feature of human participation in military forecasting is the great diversity and rapid change of tasks which confront every commander in the process of directing combat.

In speaking about the forecasting of a combat situation by a commander it would be an omission not to mention the conditions under which this is carried out. The commander's battle station is not nearly so quiet and safe a place as a scientific laboratory. Calm, detailed analysis of happenings on the battlefield and the adoption of timely and effective decisions require qualities in a commander such as boldness, courage, composure, and determination. Finally, we must mention one more characteristic feature of human participation in military forecasting, associated with the present-day "man-machine" problem.

There was a time when automation in the armed forces applied only to weapons and equipment. Now systems have emerged which include man, automatic controlling and actuating elements, and the object of control, as well as systems which include groups of people, complexes of various kinds of automatic devices, and intricate objects of control (large systems). We have already referred to associations between man and machine in this section in discussing the characteristic feature of human participation in military forecasting as it relates to reducing the time taken to produce a forecast.

Automation of control in military affairs is called upon to relieve the commander of the secondary responsibilities of making laborious and time-consuming calculations, to expedite the passage and processing of enormous volumes of information, to provide the opportunity and time for the commander to make full use of his creative abilities in working out and making optimal decisions.

In addition, automation in military affairs makes it possible to:

—remove the limitations imposed on weapons and equipment by the mental and physical resources of the people who control them;

—remove those limitations on the efficiency of the soldier's military work which are determined by the technical capabilities of weapons and combat equipment;

—achieve optimal coordination of the structure and functions of each system with a higher supersystem, interacting systems, and subordinate subsystems.

Thus, automation in military affairs in general and automation of control in particular is an effective means of improving the quality of the solution of military problems (including forecasting problems) which require a scientific approach.

NOTES

1. "Raffiniert is der Herr Gott, aber boshaft ist er nicht."
2. M. V. Frunze, *Izbr. proizv.* [Selected Works] (Moscow: Voyenizdat, 1957), II, 34.
3. M. N. Tukhachevskiy, *Izbr. proizv.* [Selected Works] (Moscow: Voyenizdat, 1964), II, 82.

Chapter 4. Models Used in Military Forecasting

1. General Principles

As follows from a consideration of the general scheme of a forecasting system, one of the most important stages of forecasting is the selection (elaboration) of a model of this process. At the same time, the specific nature of forecasting (the investigation of **future** phenomena or processes) presupposes the necessary presence of a model of the process being forecast. If in a study of the existing values of a process or phenomenon, it is possible in some cases to analyze directly the process (phenomenon) that interests us, then as soon as a forecasting problem arises, it is necessary to select (elaborate) a model of the process to be forecast in the future. The model of the process to be forecast should be selected (elaborated) on establishing an objective similarity (in one sense or another) between the phenomenon or process being studied (the original phenomenon or process) and its model. Thanks to its objective similarity to the original, the model can with a certain degree of completeness imitate the original. Sometimes in certain types of research (work on simulators, bench tests, etc.) the role of the model is determined by this function alone. In some cases simplified models of complex processes or phenomena are used. These serve mainly for the regulation of certain data about these processes or phenomena, for facilitating their apprehension and explanation (various schemes and mock-ups of a system, etc.). However, the main purpose of a model in forecasting is to obtain **new information** about the object of the forecast relating to its **future state**. Work with a model makes it possible to forecast how a given structure, technical device, or object will behave in various future situations. Tactical exercises, for example, make it possible to forecast processes connected with actual future combat operations. Models began to be used in military affairs a very long time ago. For example, military games and exercises were conducted with mock-ups of fortresses similar to real ones and on terrain similar to that where the combat operations were supposed to develop. As we know, before the storming of Ismail,

Suvorov's troops practiced methods of assault on models of the fortress walls. In World War II the Japanese constructed a model of the American naval base at Pearl Harbor in order to determine the best of various choices for a surprise attack. Similarity between the model and the original is, therefore, a necessary condition of its usefulness for studying an actual process or phenomenon. The prerequisites for objective similarity between processes and phenomena are the material oneness of the world, the unity of its space-time structure, the general interrelationship of phenomena, and the unity of the most general laws of their development. The more specific the laws which govern the development of given phenomena, the more profound the similarity between them. At the same time, the more general the laws, the more general the similarity between phenomena. For example, the processes of command and control of combat operations in various military units and formations are largely similar, both in form and content, since they are determined by one and the same objective laws of armed conflict. On the other hand, in a living organism, in human society, in technical systems, the processes of control have a similarity in form which does not extend to the content of control. This similarity is determined by general laws governing the movement of information on the basis of feedback, which are manifested identically in form only.

The broadest concept, which embraces various forms of similarity, is analogy. An analogy is an objectively existing relationship between objects in which some of their characteristics are identical and others differ from each other. Depending on the ratio of identical and distinguishing characteristics, objects are more or less similar to each other. In particular, if all the essential characteristics are uniform, while the objects themselves differ to some extent in a number of minor characteristics only, it can be said that the objects are identical. Observations of identical objects enable us to accumulate information for making decisions about the given type of objects as a whole. For example, information about faults on a piece of military equipment of a certain design, collected from places where this equipment is in use, makes possible a decision about the need for modification. However, in most cases models are not identical to the object in question. They may differ in structure, method, and conditions of functioning, as well as in terms of size and material.

Different forms of "analogy" which occur in mathematics are "similarity," "isomorphism," and "physical analogy." We shall consider some of these in more detail when we examine the question of mathematical models.

In addition to the above prerequisites for using a model in the acquisition of knowledge which are of an objective character, there are

prerequisites of a gnosiological character. The latter are unity of the information-reflective and construction-creative moments in cognition, the historically formed capacity of man to compare and abstract similar and dissimilar phenomena, to convert abstractions into independent objects of investigation, and to develop from several conceptions and ideas new conceptions and ideas [35]. In the process of perceiving and studying different phenomena and processes, man establishes characteristic similarities between them, studies models, and passes from a knowledge of these models to a knowledge of the actual processes and phenomena, using analogy, induction, and deduction. By means of analogy we form a judgment about the sameness of some properties and characteristics from the sameness of other properties and characteristics. Deduction enables us to progress from knowledge of a class of objects and phenomena to knowledge of a single object or phenomenon, while induction is a means of transition from knowledge about individual objects and phenomena to knowledge about the entire class of these objects and phenomena. Neither absolutely identical nor absolutely different phenomena and processes exist in the world. Different phenomena, processes, and objects manifest distinctive features and attributes. The degree of accuracy of the results obtained in forecasting by means of models depends on how accurately the model represents the main characteristic features and properties of the process or phenomenon being investigated.

Both physical and mathematical models are used in the solution of various forecasting problems. Physical models enable us to accomplish the process of forecasting with the use of actual physical objects. Physical modeling always is and has been used in military forecasting quite extensively. As examples, we have only to remind ourselves of the various regularly held exercises and tests of actual models of weapons and equipment. Physical models have long been used with success in laboratory research work (for example, in wind tunnel tests of aircraft and in tests of model ships in experimental tanks). In the latter case, when using the data obtained in laboratories for future real processes and objects we apply the similarity theory. The similarity theory owes its existence to the work of such famous scholars of the past as Newton, Euler, Fourier, Cauchy, Reynolds, and others. In its modern form the similarity theory is based on three theorems, one of which formulates the necessary conditions of similarity, another, the sufficient conditions, and the third (the π-theorem) defines the notion of the functional dependence between the quantities which characterize the process in the form of a dependence between the similarity criteria of which they are composed.

The similarity theory is a theory of experimentation and modeling. It answers the questions of how to set up the experiment and process the experimental data and how to correlate and extend the results to other objects. In an experiment with models constructed on the basis of the

similarity theory there is no need for an analytical solution of the problem, which, incidentally, is not always possible.

It is appropriate here to quote the words of Professor V. L. Kirpichev, the author of classic works on structural mechanics and the elasticity theory, who in 1874 first formulated and proved the theorem of the sufficient conditions of elasticity phenomena:

> It often happens that questions of dynamics or mathematical physics that differ in essence lead to equations which are completely identical in form. The analytical form of the equation proves to be identical for two or more problems, although the letters which form the terms of the equations represent in these problems completely different, often nonhomogeneous, quantities. Such a formal similarity makes it possible to use identical mathematical methods for the integration and solution of the equations; we make use of the solution obtained for one problem and apply it to others which are represented by the same equations. One problem serves as a model for several others; we can copy straight away the solution already arrived at, since it is entirely unnecessary to repeat all the previous calculations and deductions [23].

Readers wishing to familiarize themselves in more detail with the status of the modern similarity theory are referred to bibliography items [1] and [52].

Physical modeling, by virtue of its nature, enables us to give maximum consideration to the numerous factors influencing a given process. However, in some cases the use of physical models involves complex and laborious work, which, as a rule, entails considerable expenditures of time and material resources. Mathematical models make it possible to eliminate some of these undesirable features, although as a rule they are not as complete as physical models. A prerequisite for the utilization of mathematical models, in research in general and in forecasting in particular, is unity of the laws of nature, which unite in some respect widely separated phenomena, and identity of the form of the equations describing them. Emphasizing this, V. I. Lenin wrote that "the unity of nature is revealed in the 'striking similarity' of differential equations relating to different ranges of phenomena."[1]

Let us consider in more detail what is meant by a mathematical model of a process. Mathematical modeling is based on a mathematical version of the concept of "analogy"—isomorphism. The phenomenon of isomorphism signifies similarity of the form of various phenomena and processes which differ qualitatively. It follows from this that in studying one isomorphic phenomenon or process we can extend the conclusions obtained as a result of this study to another isomorphic phenomenon or process. However, here we must be guided by certain rules for the transition from one phenomenon to another. The fact is, as we have already

mentioned, absolutely identical phenomena, processes, and objects do not exist in our world. Isomorphism refers to the unity and relationship of various phenomena within certain limits only. Therefore, it is possible to analyze one phenomenon by studying another within certain limits only, even though the latter is of a similar form and structure. A mathematical model must take into account the principal aspects and interrelationships of a given phenomenon by means of certain mathematical relationships and thus, in this sense, a mathematical model is an abstraction from reality. A model should be constructed for the solution of a specific research problem. Depending on the purpose and objectives of the investigation, some relationships and aspects of a phenomenon will be significant in one case and others in another. Experience proves that attempts to construct a universal mathematical model that accounts for every possible relationship and aspect of the phenomenon in question results in unwarranted complication of the model, which in some cases makes it unsuitable even for the solution of the problems at hand.

The selection and substantiation of a mathematical model of a process to be forecast is a problem whose difficulty is determined by whether and to what extent processes similar to the one being forecast have been studied, whether the given specific process is accompanied by uncertainties, etc. For example, there are deterministic processes for the parameters of which there is complete a priori information. In such cases the forecasting problem presents no difficulties at all. To give an actual case, by applying the laws of mechanics it is an easy matter to forecast the trajectory of the center of mass of a rigid body in a predetermined resistance-free gravitational field, given the initial velocity and coordinates. It is also possible to conceive models of deterministic processes when we do not possess full a priori information about the parameters of the model (when the initial conditions for certain differential equations are unknown, when certain coefficients of differential equations are unknown, etc.). For instance, if under the terms of the above example the initial conditions of the motion of a rigid body were unknown, it would be necessary to measure the coordinates and velocity of its center of mass at some point of the trajectory or its coordinates at two points of the trajectory. Forecasting the trajectory of a rigid body in the presence of deterministic resistances which are not known a priori entails the use of a more complex model, since it must take into account the effect of the resistances on the trajectory of the rigid body. However, even in this case the problem of forecasting presents no great difficulty; it is necessary only to measure the velocity and the coordinates at several (more than two) points of the trajectory. Consequently, if we are solving a problem of forecasting a physical process which we understand well, i.e., the form of its model is known to us, and the information about this process is not distorted by various kinds of interference, any difficulties we may encounter will be concerned with calculation only.

In cases where the model of the process is not known a priori, but the process is determined and the information about it undistorted, the problem of forecasting is normally resolved successfully.

A more difficult problem is the selection and substantiation of a model of a process about which we have only limited information; for example, "the process is stable," "such and such a characteristic of the process is a nondecreasing (nonincreasing) function of time," "the values which characterize the process are nonnegative," etc. Finally, when nothing is known about the form of the model of a process a priori and the available information about it is distorted by various kinds of interference, the problem of selecting and substantiating the model becomes a complex task requiring experience and skill on the part of the investigator.

The use of mathematical models in forecasting possesses undoubted advantages over the use of physical models. First and foremost, there is the relative simplicity and convenience of working with mathematical models. The use of modern computers makes it possible to cut down considerably the time taken for mathematical modeling (compared with physical modeling) and, in addition to this, to analyze rapidly a large number of variants with different basic data and initial conditions, which for some processes in physical modeling is either completely impossible or entails considerable expenditures of time and resources. There are complex processes and phenomena (including those encountered in military affairs) which, because of the complexity of the interrelationships of their component subprocesses, cannot be described sufficiently fully in mathematical terms. One of the methods of forecasting such processes is the combined use of mathematical and physical modeling (mathematical modeling of combat operations and exercises, mathematical calculations of the parameters and characteristics of missiles and practice launches, mathematical calculations of the design and parameters of aircraft, the testing of models in wind tunnels, test flights, etc.). In addition to this, it is necessary to use combined methods of forecasting which incorporate both mathematical and heuristic methods in which the models of the processes under study are formed and "operate" in the mind.

Such are the general principles relating to models and their use in the research process of forecasting.

We shall now dwell in more detail on the requirements which models of processes to be forecast must meet, processes in general and military processes in particular.

2. Requirements Which Models Must Meet

The basic requirement which a model of a process to be forecast must meet is **accuracy of presentation of the change process of the char-**

acteristic in question. In this case the model must reflect correctly the influence of the basic, most essential values and factors on the characteristic in question. In particular, forecasting models must take adequate account of time. This applies especially to models of processes of armed conflict, as the most complex and multifaceted processes, all of the values and factors in which it is practically impossible to calculate. The model should represent a judicious combination of the required **completeness** and **simplicity** of use and calculation. These two requirements are, of course, contradictory. On the one hand, making the model infinitely detailed will inevitably result in its becoming too complex, which, naturally, complicates work with it and in some cases makes it impossible. On the other hand, attempts to simplify the model to the maximum extent will mean that a number of factors are not taken into account, which may have a serious effect on the process being forecast.

The model should be such as to permit rapid **necessary changes** to be made in it, since one can never be absolutely sure that the first version of a model will be the best one and that it will not require adjustments while in use and after further analysis of the process being forecast.

In a number of cases the model must ensure **greater rapidity of action** than the process under investigation. This is particularly important when it is necessary to calculate a large number of parameters of processes actually taking place during long periods of time. It is not difficult to imagine what would be involved in, for example, the modeling on a full time scale of, say, 200 realizations of combat operations taking place during the course of 24 hours.

In a good many cases, **limitation of the cost** of a model is an extremely important requirement. It is particularly important to take this into account in the physical modeling of costly processes (for example, missile proving launches, troop exercises, etc.). Such, in general terms, are the most important requirements which models of processes to be forecast may have to meet.

We shall now pass on to a consideration of the types of models in terms of features and attributes.

3. Classification of Models

Models of processes to be forecast can be classified according to the most diverse features. In the first section of this chapter we considered the division of models depending on the **correspondence of the physical nature** (the "material") of the model, into **physical, mathematical,** or a combination of both, the last mentioned being the one most often encountered in literature on model construction and modeling.

A number of authors also refer to **cybernetic models**. Cybernetic modeling is used in dealing with physically dissimilar objects. It does not necessarily reproduce the internal structure of the objects in question, but it certainly reproduces the functional arrangement of the control processes in the object being forecast. As an example of the use of a cybernetic forecasting model we can cite the ALFA recognition system which predicts the height of ocean waves and river bottom relief. For more detailed information about cybernetic models used in forecasting the reader is referred to bibliography items [19], [20], and [21]. An analysis of the results of the research described in these works shows that in some cases cybernetic forecasting systems can be used to forecast random processes with a fair degree of accuracy, however, it should be noted that achieving cybernetic forecasting systems is an extremely complicated matter.

The next feature according to which models can be subdivided is the **type of object being forecast**.

The following can be classified according to the type of object being forecast:

—models of processes of armed conflict;
—models of the functioning of technical devices;
—models of the development of production;
—models of the development of science and technology;
—economic models;
—demographic models;
—social models;
—models of political situations, etc.

Within each type models can be distinguished as to the level of investigation and the **nature of the process described**. For example, models of processes of armed conflict can be:

—models of general questions of armed conflict;
—models of specific questions directly related to armed conflict;
—models of the functioning of complexes or items of military equipment.

Models of the last mentioned type are associated with the operation of military equipment. Here we can include processes of the control and guidance of mobile objects, processes of the mechanical, chemical, and radiation effect of injurious substances on personnel and military equipment, processes in the transmission, reception, and processing of information, etc.

Models of individual aspects of armed conflict are concerned with different forms and phases of combat operations and belong to the op-

erational-tactical division of military forecasting. And, finally, general aspects of armed conflict are concerned with armed conflict as a phenomenon in itself and belong to the military-strategic division of forecasting. Models of these processes in military affairs are in turn subdivided into several corresponding submodels, which detail still further the questions under consideration. For example, depending on the degree of itemization and completeness of analysis, models of the second type can be divided into the following currently accepted models:

—stochastic duels;
—combat operations engaged in by groupings of forces without taking into account their distribution and movement in space;
—operations engaged in by groupings of forces, distributed in space, without taking into account their movements;
—operations engaged in by groupings of forces, distributed in space and moving in time.

It should be noted that this kind of subdivision is dictated mainly by research requirements. Thus, stochastic duel models enable us to resolve certain problems connected with forecasting the efficiency of weapons models. Models of groupings of forces distributed in space and time make it possible to solve very important problems concerned with the dynamics of combat operations: the rate of movement of the combat contact line, the losses sustained by the opposing sides and their variation in the course of the battle, the structure and density of combat formations, etc.

Models may be classified, in terms of the **nature of the occurrence** of the process being forecast, as models of evolutionary development, models of revolutionary development (abrupt changes in the parameters of the process being forecast), and models which include elements of both evolutionary and revolutionary development.

Here the biggest difficulty is the investigation of processes of revolutionary development, particularly the forecasting of the times when abrupt changes will occur and the magnitude of these changes. In view of their great importance, these questions will be discussed separately in chapter 7.

Models can also be classified according to the **form of their description**. Depending on their description, models can be either verbal (descriptive) or mathematical.

Verbal models are represented by descriptions of encountered phenomena, types of activity, or systems. Mathematical models are characterized by a description of a given process or phenomenon by one of the mathematical methods.

Depending on the **form of mathematical description**, models can be subdivided into models described by differential equations or systems of differential equations (linear, nonlinear, partial derivative, delayed argument), models described by algebraic and transcendental equations or systems of these equations, which relate the value being forecast to a number of other values.

Models described by differential equations contain richer information than models described by algebraic and transcendental equations, since they make it possible to analyze dynamic questions relating to the development of the process being forecast (questions of stability and quality), and in some cases (differential equations with a delayed argument) make it theoretically possible to solve qualitatively new problems (for example, the forecasting of abrupt changes). And, although in some cases, the problem of forecasting processes described by differential equations cannot be solved analytically, this does not, thanks to modern computers, present a major difficulty.

Depending on the presence and level of uncertainties involved in processes which are the subject of forecasts, models can be classified as models of deterministic (nonrandom) processes and models of stochastic (random) processes.

As we have already indicated, deterministic processes are very rare in forecasting problems, and for this reason they are not of great practical interest. Besides, the forecasting of deterministic processes is, as a rule, a trivial problem. In practice (especially in military affairs) we are concerned mainly with stochastic processes.

Models of stochastic processes are in turn subdivided into models for calculating estimates of expected values of processes (models of the dynamics of averages for mass phenomena in military affairs, economics, and biology) in continuous (differential equations) or discrete form (equations in finite differences), probability models[2] in continuous form (the queueing theory, stochastic duels, etc.), or discrete form (Markov chains); models of statistical trials (the Monte Carlo method). The most complete and detailed of the models of stochastic processes belong to the first group. The feature of the process which we shall study at a future moment of time, using probability models, can be characterized by a certain quantity (the probability of the event) which may assume values restricted to certain limits. Random processes, which it is impossible (at the present stage) to study in depth and represent by models of the first group, or which it is difficult to study and describe in detail, are forecast by means of the statistical trials method, known as the Monte Carlo method. This method owes its name to the game of roulette, widely

played in the gambling houses of Monte Carlo. Anyone wishing to obtain more detailed information about this method is referred to bibliography item [8].

In addition to the general classification of models described above, individual types of these models can be classified. For example, analytical models which describe the process being forecast in the form of algebraic and transcendental equations can be subdivided according to the **type of functions** which characterize the deterministic basis of this process:

—polynomial (particularly linear and quadratic) models;
—trigonometric models;
—exponential models, etc;
—models which incorporate combinations of the above models.

The classification of models of processes for forecasting considered in this section is, of course, not exhaustive. However, it does serve to give an idea of the variety and multiplicity of models used in military forecasting.

4. Models Described by Algebraic and Transcendental Equations

First we shall consider the simplest mathematical models in which the quantity y to be forecast is clearly expressed by other parameters of the model:

$$y = f(\bar{a}, \bar{x}) + \varphi(\bar{b}, \bar{x})\eta, \tag{1}$$

where

$f(\bar{a}, \bar{x})$ and $\varphi(\bar{b}, \bar{x})$ = certain deterministic functions;
$\bar{x} = (x_1, x_2, \ldots, x_m)$ = certain known parameters, one of which is time t, the remaining parameters may be various known quantities which influence the development of the quantity y being forecast;
$\bar{a} = (a_1, a_2, \ldots, a_n)$, $\bar{b} = (b_1, b_2, \ldots, b_p)$ = unknown parameters (coefficients) which are to be determined;

η is a random process with zero expected value. Function $f(\bar{a}, \bar{x})$ is the deterministic base of process y being forecast. It characterizes values that y would have if it were not subjected to the action of random interference η. Function $\varphi(\bar{b}, \bar{x})$ characterizes the limitations imposed on the action of random interference η. In different practical problems other assumptions may be made about η (apart from its expected value being equal to zero):

—that η always has a constant variance;

—that η usually has a normal distribution;
—that η is very often a noncorrelated random process.

The most widely used model at the present time is one with additive (cumulative) interference of the form:

$$y = f(\bar{a}, \bar{x}) + \eta, \tag{2}$$

which is a particular case of model (1), given that

$$\varphi(\bar{b}, \bar{x}) \equiv 1. \tag{3}$$

The case $\varphi(\bar{b}, \bar{x}) = 0$ corresponds to a deterministic process and, as already indicated, is of no great practical importance.

Also encountered in practice are models of the form

$$y = f(\bar{a}, \bar{x})\varphi(\bar{b}, \bar{x})^{\eta}, \tag{4}$$

which in certain cases (when $f(\bar{a}, \bar{x}) > 0$, $\varphi(\bar{b}, \bar{x}) > 0$) can be reduced to model (1) by logarithmation:

$$\ln y = \ln f(\bar{a}, \bar{x}) + \eta \ln \varphi(\bar{b}, \bar{x})$$

or

$$y^{*} = f^{*}(\bar{a}, \bar{x}) + \varphi^{*}(\bar{b}, \bar{x})\eta.$$

Processes characterized by models of the type shown in (4) above are frequently encountered in economics research.

We shall now discuss the types of deterministic bases and processes most frequently used in practice. We shall begin by examining models in which $\bar{x}$ has a dimension equal to unity, i.e., when the value being forecast is a function of only one known parameter—time t:

$$\bar{x} = t.$$

Here model (2) can be written in the form

$$y = f(\bar{a}, t) + \eta. \tag{5}$$

The simplest model of this type is one with a constant deterministic base

$$y = a + \eta, \tag{6}$$

i.e., a model, the deterministic base of which is a constant

$$f(\bar{a}, t) = a. \tag{7}$$

The model with a constant deterministic base (6) is very widely used, since it describes fixed random processes, widely represented in practice. Observations of a process with this model at different moments of time represent a random selection of a certain distribution with an expected value which is independent of time.

The deterministic base of a **linear model**

$$y = a_0 + a_1 t + \eta \tag{8}$$

can be represented in the form

$$f(\bar{a}, t) = a_0 + a_1 t. \tag{9}$$

This model is used to describe processes which develop at a constant speed a_1.

Example 6. The simplest means of calculating the lead in firing at an aerial target is a computation in which the calculation of the target's future position is made on the basis of the assumption that it will move uniformly and in a straight line during the time the projectile is on its way to the lead point. In this case the coordinates of the target are calculated in accordance with the model:

$$x = x_0 + v_{0_x} t;$$
$$y = y_0 + v_{0_y} t;$$
$$z = z_0 + v_{0_z} t.$$

where x_0, y_0, z_0, v_{0_x}, v_{0_y}, v_{0_z} are, respectively, the coordinates and speed of the target at the moment of firing (figure 7).

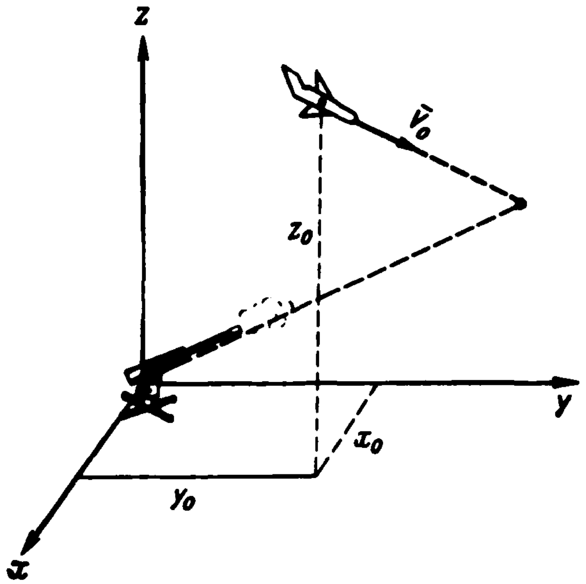

Figure 7. Example 6.

A quadratic model

$$y = a_0 + a_1 t + a_2 t^2 + \eta \tag{10}$$

has a deterministic base of the form

$$f(\bar{a}, t) = a_0 + a_1 t + a_2 t^2. \tag{11}$$

This model, in addition to the rate of change of the value being forecast, also takes into account its constant acceleration a_2. Such a model can be used under the same conditions as those in the previous example, if the acceleration of the target is constant from the moment the shell is fired until the moment of impact. Here the lead would be computed on the assumption that the target would have a constant acceleration during the time the shell was on its way to the lead point.

These three types of deterministic bases of processes (invariable, linear, and quadratic) are prevalent individual cases of a more general type of deterministic base—the **polynomial**:

$$f(\bar{a}, t) = \sum_{i=0}^{n} a_i t^i, \tag{12}$$

which in the general case is a polynomial of the nth power. Consequently, a model with an invariable deterministic base is a polynomial of zero power, one with a linear base is a polynomial of the first power, and one with a quadratic base is a polynomial of the second power.

The power of a polynomial can in certain cases be selected on the basis of a physical analysis of the process. Thus, the movement of the target in the above example, with constant linear acceleration, can be represented by a polynomial of the second power, and variation of its speed, by a first power polynomial.

In cases where the process being forecast has been insufficiently studied, the selection of the power of the polynomial should be approached with great caution. Actually, by increasing the power of the polynomial, the process being studied can be described with the necessary accuracy in the sector of observation. In particular, the power of a polynomial of a deterministic process can be accurately determined if this process is observed in the following way.

Calculate the differences:

—first difference

$$\Delta_t y = y(t) - y(t-1); \tag{13}$$

—second difference

$$\Delta_t^2 y = \Delta_t y - \Delta_{t-1} y = y(t) - 2y(t-1) + y(t-2)$$

and so on, where $y(t-i)$ is the value of the process y being observed at moment of time $t-i$.

For a polynomial of the nth power the equality to zero of $n+1$ difference will obtain, i.e., $\Delta_t^{n+1} y = 0$. Here the polynomial will pass through all the points to be observed. However, real processes are distorted by interference. Because of this, attempts to construct a forecasting polynomial which passes through all the points to be observed usually result in imprecise forecasts.

Example 7. Let us assume that we are interested in forecasting the movement of an enemy tank column which has left point A (figure 8). The enemy's real intention—to reach point B—is unknown to us. Observing the movement of the column, we note its position at point 1 (x_1, y_1) at moment of time t_1 and at point 2 (x_2, y_2) at moment of time t_2. Knowing that he is under observation, the enemy executes a diversionary maneuver to point 3 (x_3, y_3), which we fix at moment of time t_3.

If the enemy's subsequent intentions are judged from these observations, then, drawing a polynomial of the third power,

$$x = x_A + a_1 t + a_2 t^2 + a_3 t^3;$$

$$y = y_A + b_1 t + b_2 t^2 + b_3 t^3$$

through all four observation points (A, 1, 2, 3), we shall come up with the erroneous forecast that the enemy intends to reach point C.

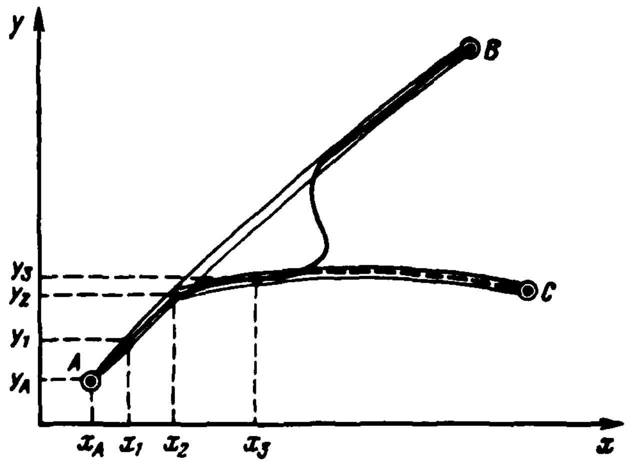

Figure 8. Example 7.

The next example of type (1) models is represented by **exponential models:**

$$y = ae^{bt} + \eta, \tag{14}$$

the deterministic base of which has the form

$$f(\bar{a}, t) = ae^{bt}. \tag{15}$$

These models describe processes in which the rate of change of the parameter being forecast is proportional to the size of this parameter. A characteristic feature of this type of model is the invariability of any two pairs of equidistant readings. In particular, readings separated by an interval Δt are related as

$$\frac{ae^{b(t+\Delta t)}}{ae^{bt}} = e^{b\Delta t}.$$

Consequently, the succeeding (in terms of the Δt) value of the quantity described by expression (15) is equal to the previous value multiplied by the constant $e^{b\Delta t}$.

Example 8. As an example of a process the deterministic base of which can be described by an expression in the form of (15), we can take the relation of the average horsepower of a motor vehicle per transport facility as a function of time (figure 9) [69]. The figures were obtained by dividing the total horsepower by the total transportation facilities and are represented in logarithmic coordinates.

Exponential models are a particular case of the more general class of **logistic models,** the deterministic base of which takes the form

$$f(\bar{a}, t) = \frac{a}{1 + be^{-ct}}, \tag{16}$$

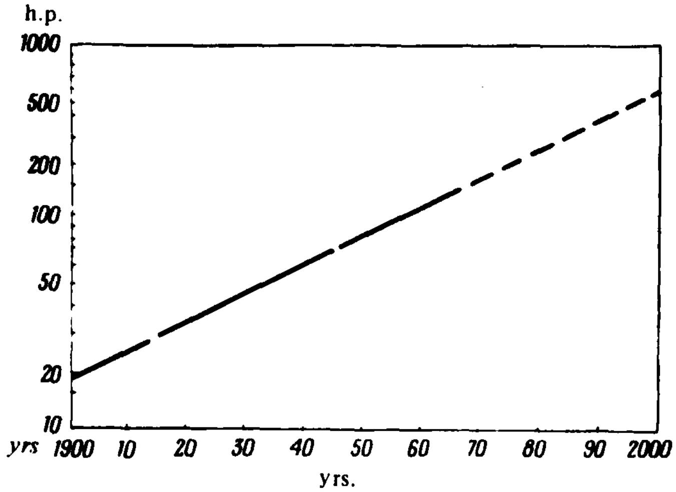

Figure 9. Average Horsepower of Motor Vehicles (Figures Obtained by Dividing Total Horsepower by Total Transportation Facilities).

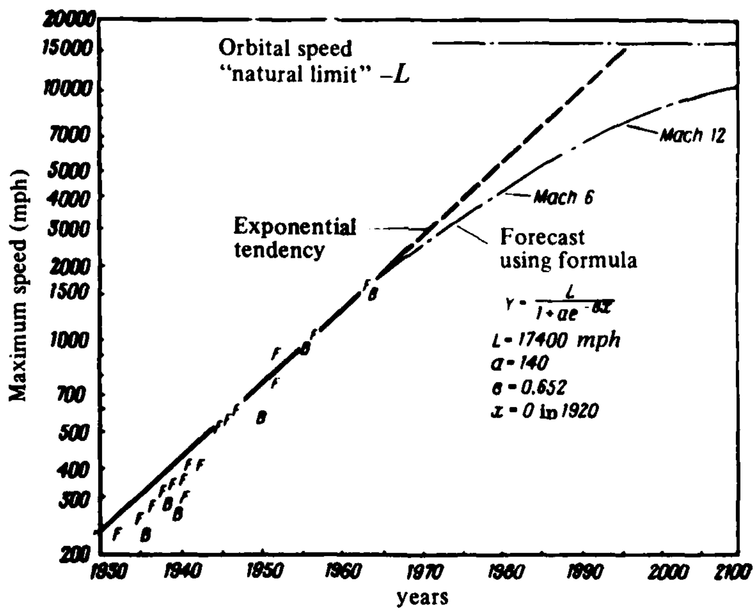

Figure 10. Trend of U.S. Military Aircraft Speeds.

and is represented by an S-shaped curve with asymptote a for $t \to \infty$.

On fulfillment of the condition

$$be^{-ct} \gg 1,$$

which can occur, given small t and $b > 1$, we obtain, as a particular case, a model of the form of (15).

Example 9. As an example of a process which can be described by a model with a deterministic base in the form of a logistic curve, we can take the increase in the speed of U.S. military aircraft as a function of time (figure 10), represented in the form of logarithmic coordinates [69].

Processes subject to periodic changes can be represented in the form of **trigonometric models.**

In the general case the form of the deterministic base of a process may be written as follows:

$$f(\bar{a}, t) = \frac{a_0}{2} + \sum_{k=1}^{n} (a_k \cos k\omega_0 t + b_k \sin k\omega_0 t), \quad (17)$$

where $w_0 = \frac{2\pi}{T}$,

T is determined by the interval of the expansion of the function in a trigonometric series

$$-\frac{T}{2} < t < \frac{T}{2}.$$

We should note here the selection of the number of expansion terms n, analogous to that concerning the selection of the power n of a polynomial model. If from a physical analysis of the process it is not possible to establish the value of n, the selection of the number of expansion terms should be made very carefully, since computation difficulties increase with an increase in n and, what is more important, the possibility of decreasing the effect of random interference is lost.

Readers who are interested in obtaining more detailed information about hidden periodicities in a given process are referred to the book by M. G. Serebrennikov and A. A. Pervozvanskiy [47].

Processes characterized by trigonometric models are encountered, for example, in the study of oscillations in various mechanical systems, in the forecasting of meteorological factors, the seasonal demand for certain types of commodities, etc. In particular, great interest is shown in the discovery of periodical variations as applied to statistical time series in economics [17].

Example 10. The curve shown in figure 11, which is based on information given in bibliography item [70], describes the number of passengers transported each month on international airlines in 1949. Analysis of this curve reveals a clearly expressed harmonic component in the deterministic base of the process in question.

Included among models in which the quantity being forecast is clearly expressed by other parameters: $\bar{x} = (x_1, x_2, \ldots, x_n)$ are **regressive models:**

$$f(\bar{a}, \bar{x}) = \sum_i a_i x_i. \quad (18)$$

In these models the unknown parameters of a_i to be determined **enter linearly.** It should be noted that, in addition to known quantities of x_i, a different set of independent functions of x_i may enter:

$$f(\bar{a}, \bar{x}) = \sum_j a_j \varphi_j(\bar{x}). \qquad (19)$$

There are also models in which unknown parameters **enter nonlinearly,** for example,

$$f(\bar{a}, \bar{x}) = a_0 + a_1 \sin a_2 x_1 + a_3 e^{a_4 x_1}.$$

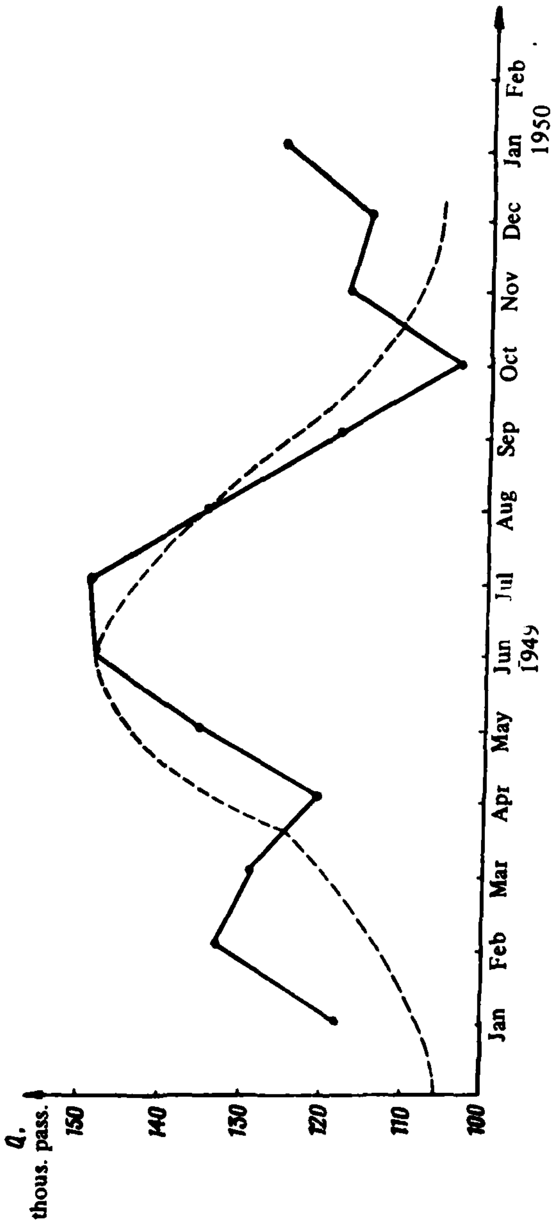

Figure 11. Example 10.

In this case the problem of determining these unknown parameters is considerably more complex. We shall dwell in more detail on these models, as well as models in the form of (18), in chapter 7, in which we shall consider mathematical methods of forecasting.

In some cases, for describing more complex processes, we can use combined models which are various combinations of the models considered above. However, as we have already mentioned, it is important to remember that complication of the model can be justified only in those cases where the investigator has a clear conception of the essence of the process being forecast and such complication is necessary for revealing important aspects of the phenomenon being forecast.

Several forms of algebraic and transcendental models have been considered in which the quantity being forecast is clearly expressed by known parameters. A forecasting problem in this case essentially amounts to an estimate of the unknown coefficients $\bar{a}$ in the observation sector with subsequent calculation of the value of the quantity being forecast for given values of the known quantities $\bar{x}$.

In the more general case the quantity y being forecast can be expressed implicitly by unknown coefficients and known parameters:

$$F(y, \bar{a}, \bar{x}) = 0. \qquad (20)$$

Here y and F can be multidimensional.

Algebraic models can be used to describe combat operations also. Let us consider an example of one such model [74].*

Example 11. Let us consider a model of a battle between a motorized rifle or tank formation on one side and corresponding forces on the other side (in a nonnuclear situation in the West European Theater of Operations; engagement period 12 hours per day).

Input data for the model are:
- —number and composition of forces on each side;
- —type of operations engaged in by each side (attack, defense, delaying action,[3] and meeting engagement);
- —type of terrain (four types, ranging from open country to mountainous wooded country, and terrain on which there are natural obstacles);
- —the state of the forces at the start of the 12-hour engagement (number of men and quantity of equipment);
- —position of combat contact line.†

The model has three kinds of input data:
- —the result of the engagement (win, lose, draw[3]);
- —the state of the forces after the engagement;
- —the movement of the combat contact line.

*[The reader is urged to consult the bibliography and read the English language original to gain the opportunity to deal with more familiar terminology—U.S. Ed.]

†[The original English reads "forward edge of the battle area"—U.S. Ed.]

The form of the algebraic model, which provides a means of obtaining the indicated data is written:

$$E = \sum_{i,j,k} \{F_m (N_i K_i M_i + N_j K_j M_j) + F_a K_k M_k\},$$

where

E = the relative index of effectiveness of the battle;
F_m = a coefficient of nonlinearity which takes into account the effect of the coordination of maneuver battalions, which falls within the range 1.0–0.8;
$N_{i,j}$ = the number of combat units (i—tanks, j—infantry);
$K_{i,j,k}$ = the effectiveness of a combat unit, depending on its state (attack, defense, etc.) (i—tanks, j—infantry, k—artillery);
$M_{i,j,k}$ = a coefficient which takes account of the terrain;
F_a = coefficient of nonlinearity, which takes account of the presence of the optimal number of artillery battalions.

Let us consider this model in more detail.

The expression for E is a formula which utilizes expertly determined coefficients of combat effectiveness $K_{i,j,k}$, for the tanks, infantry, and artillery of both sides, for all instances of combat operations. It is also possible by means of coefficient F_m to allow for such nonlinearities as nonoptimal coordination of infantry and tanks in fulfilling a given combat mission, or too much or too little air support. The quantity E is calculated for sides I and II and then compared. Depending on the ratio E_I/E_{II}, win, lose, or draw is computed for the sides. A draw is assumed in a case where the forces are approximately equal and when comparison shows that both sides suffered heavy losses. The coefficients of relative combat effectiveness provided by experts for different types of combat operations are given in table 1.

Table 1. Coefficients of Relative Combat Effectiveness of Sides I and II.

Branch of troops	Defense of previously prepared position		Attack on hastily prepared position		Meeting engagement	
	Battalion of side I	Regiment of side II	Battalion of side I	Regiment of side II	Battalion of side I	Regiment of side II
Tanks	30	53	24	42	16	28.1
Infantry	18	35	12	25.6	6	17.2
Artillery	12	12*	9	9*	6	6*

* Battalion of side II

The coefficient of a particular unit's combat effectiveness, which takes into account its potential and limitations, defines the relative effectiveness in fulfilling a given combat mission (relative to that of all the existing forces). An arbitrary reference value of 30 is taken as the coefficient of relative combat effectiveness of a tank battalion of side I in defending a previously prepared position.

Here are some of the reasons for the values given.

It is assumed that the most preferred weapon in an organized defense is the tank. The potential of mechanized infantry is slightly less than two-thirds that of tanks. Under these conditions artillery has only about two-thirds the combat effectiveness of mechanized infantry. Starting with the fact that the combat unit on side II is a regiment, a comparison was made between the combat effectiveness of an infantry and tank regiment of side II and the battalions of side I. For example, in a tank regiment of side II there are 95 heavy tanks and in a tank battalion of side I, 54. Therefore, the combat effectiveness of a tank regiment

of side II is 1.75 times that of a tank battalion of side I. An approximate equivalency exists for the respective infantry units. However, owing to the fact that an infantry regiment of side II includes a tank battalion, the combat effectiveness of an infantry regiment of side II (35) is considered to be equal to the combat effectiveness of an infantry battalion of side I (18) plus the combat effectiveness of a tank battalion (17).

The combat effectiveness of the artillery of sides I and II is assumed to be approximately equal. Side II has the advantage in range, ammunition combat power, and rate of fire; side I has the advantage in firing accuracy, mobility, and crew protection facilities.

The effect of the type of terrain is allowed for as follows. Depending on the type of terrain, all the combat units are allocated coefficients $M_{i,k}$, by which their combat effectiveness is reduced by values varying between 1 and 10.

Coefficient 10 obtains for terrain of type *A* (open country). For type *B* (hills and forest) the coefficient for tanks is reduced by 30 percent, while the reduction for infantry is only 10 percent, since the latter can perform the mission on foot. The coefficient for artillery does not change. The coefficient for tanks is substantially smaller on type *C* terrain (steep slopes, densely wooded and swampy terrain). At the same time, the coefficients for infantry and tanks are reduced, though to a lesser degree. The most difficult terrain for attacking forces is type *D* (terrain with major obstacles, such as wide rivers). The combat effectiveness of defending forces on such terrain increases, since they can use these obstacles to their advantage.

Coefficients of nonlinearity F_m and F_a are introduced on the basis that for each combat mission and type of terrain there is an optimal combination of maneuver units (tanks and infantry) and fire support (artillery and air support). If there is any deviation from these optimal combinations, then the effectiveness of the combat units is reduced by up to 20 percent.

The following is an assessment of the output characteristics of the model.

1. *The results of the engagement.* The victor in the attack is assumed to be the side, the *E* of which exceeds the *E* of the defending side by not less than 25 percent. The attacking side is assumed to have been defeated if its *E* is less than 95 percent of the enemy's *E*. A draw is assumed in the interval between 0.95 and 1.25.

2. *Movement of the combat contact line.* The average movements *x* of the combat contact line in different cases are given in table 2.

3. *The state of the combatants' forces after the engagement.* This state is characterized by a number between 0 and 100, which defines the capacity of battalions to carry out an attack, defense, or delaying mission. The state of the forces is determined at the end of each 12-hour engagement. The losses in men and materiel depend on the type of combat operations and their outcome. The state of the forces at the start of a new 12-hour engagement is determined by the results of the previous engagement, which impose limitations on the combat capabilities of the sides. It is assumed that a battalion is capable of carrying out any of the combat missions if its state is characterized by a figure between 65 and 100. If the state of a battalion is denoted by a figure less than 65, it loses the ability to attack. If there are no reinforcements, the capacity for defense is maintained down to the 50 mark. Below this a battalion's capability is reduced to that of fighting a delaying action. The loss of the capacity to carry out a particular combat mission depends on the initial state of the forces before the engagement. The dependence of the relative extent of losses *L* on initial state *S* takes the form $L = 100\ d/S$ and is shown in figure 12, from which it follows that,

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Table 2. Movement of Combat Contact Line x Over 12-hour Period in km.

Type of terrain	A			B			C			D		
Type of combat operations	win	draw	lose	win	draw	lose	win	draw	lose	win	draw	lose
Overcoming delaying action* ...	14	5	2	10	4	1	3	1	0	2	1	0
Attack on hastily prepared position	6	0	0	4	0	0	2	0	0	1	0	0
Attack on previously prepared position	3	0	0	2	0	0	1	0	0	1	0	0
Meeting engagement	2	0	−2	1	0	−1	1	0	−1	0	0	0

* This term is used in foreign literature.

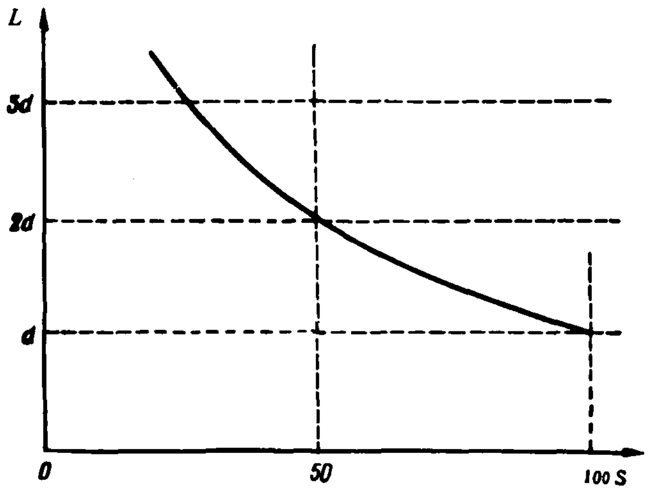


Figure 12. Determining the Relative Losses.

Table 3. Value of d for Different Combat Operations.

Type of combat operations	Outcome		
	Win	Draw	Lose
Engagement with enemy fighting delaying action ..	2	3	4
Attack on hastily prepared position	8	10	10
Attack on previously prepared position	12	15	15
Meeting engagement	4	6	5
Defense of previously prepared position	5	7	10
Defense of hastily prepared position	6	8	7
Delaying action	2	3	4

Note. If the correlation of the forces of the attacking and defending sides is characterized by a ratio greater than 2, d should be multiplied by ⅔ for the attacking side and ½ for the defending side; if it is less than 0.4, d should be multiplied by 2 and by ½, respectively.

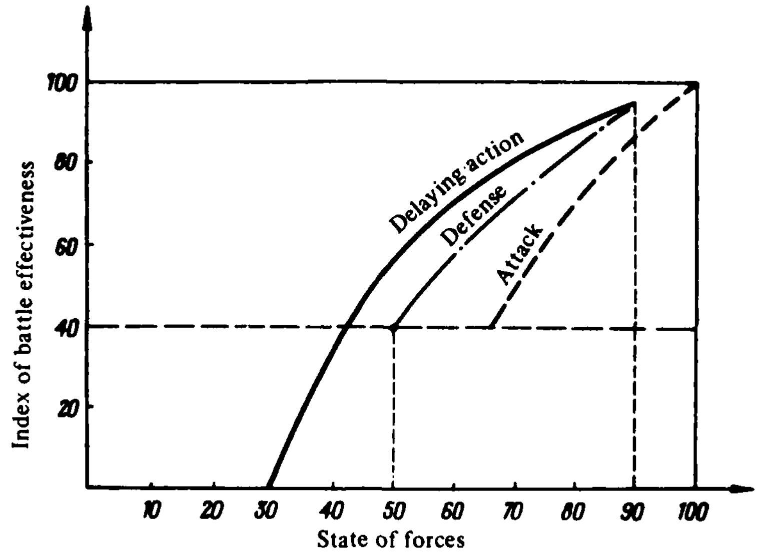


Figure 13. Index of Battle Effectiveness as a Function of the State of the Forces.

for example, the relative losses for an initial state of 50 are double the losses for an initial state of 100. Coefficient d represents a fixed loss (for an initial state of 100), values of which for various combat missions and engagement results are given in table 3.

The dependence of the index of effectiveness of battle on the state of the forces is shown in figure 13.

Using this model, we can forecast the results of 24 hours of an engagement and, if we include the forecast of the supply of reserves, for a longer period. A practicable scheme for utilizing the data provided by this model for making the battle plan is shown in figure 14.

This sort of model can be very useful for staff estimates (given coefficients prepared beforehand by qualified military experts), since it is "simple to use" and does not entail the use of complex computer equipment.

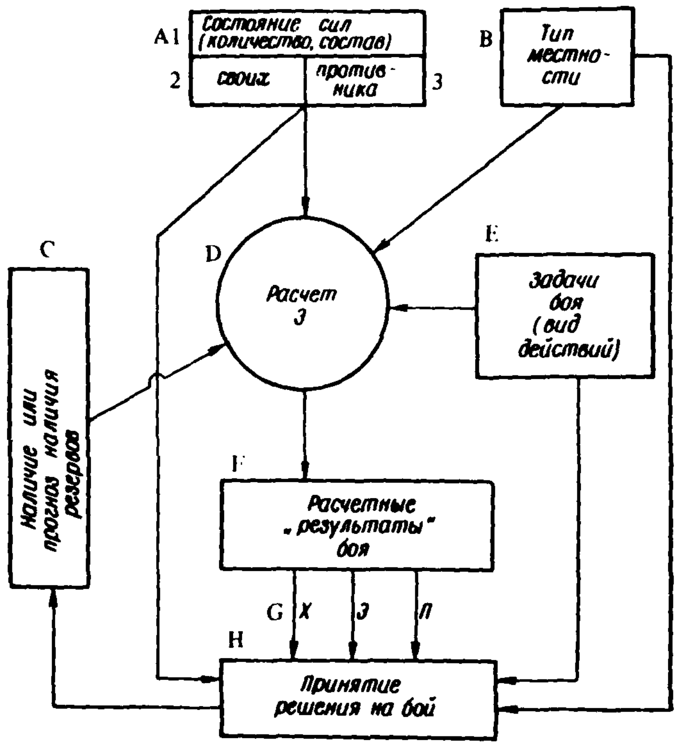
5. Probability Models

In the preceding section we examined certain models described by algebraic and transcendental equations, which are based on a physical analysis of the nature of the process being forecast and are analytical expressions which relate the quantity being forecast to a number of other quantities.

Key:

A1 - State of forces (number, composition)
2 - one's own
3 - the enemy's
B - Type of terrain
C - Presence or forecast of presence of reserves
D - Calculation of E
E - Combat missions (type of operations)
F - Calculated "results" of battle

G - *Kh E P**
H - Adoption of battle plan



*[All illustrations accompanying Example 11 were adapted from the original American article except this one. These three items are Russian symbols, and their meaning is not clear—U.S. Ed.]

Figure 14. Using a Model to Formulate a Battle Plan.

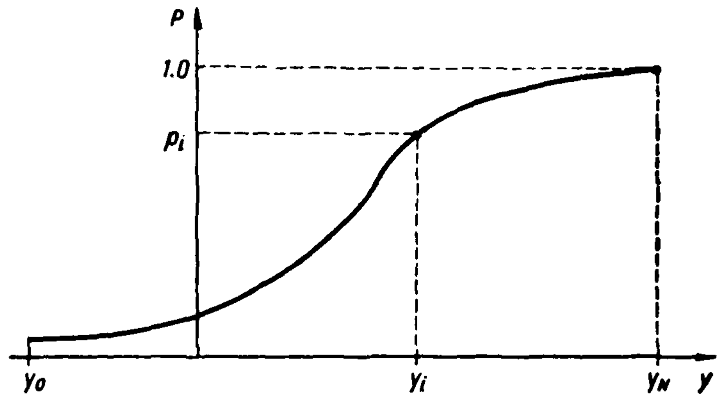


Figure 15. Probability Distribution Function.

Probability models enable us to calculate the probability that a future value of a parameter of the process being forecast will be less than a specific figure (figure 15), for example, the probability that $y<y_i$,

$$P_i = P(y < y_i). \tag{21}$$

Quantity y can be found within the limits

$$y_0 \leqslant y \leqslant y_n,$$

since, according to figure 15

$$P(y < y_0) = 0 \text{ and } P(y < y_n) = 1.$$

The distribution curve of a continuous random quantity y shown in figure 15 is a graph of the distribution function *P(y)*, sometimes also known as an integral distribution function.

A distribution function exists both for continuous and discrete random variables and is a universal characteristic of random variables, since it characterizes them completely from the probabilistic point of view. A diagram of a distribution function in the general case is a diagram of a nondecreasing function, whose values start at 0 and reach a maximum of 1. In individual cases the function may have abrupt changes (discontinuities).

The distribution function of a discrete random variable is always a discontinuous step function (figure 16), the abrupt changes of which occur at points which correspond to possible values of the random variable, and equate to probabilities of these values. The sum of all the abrupt changes of function *P(y)* is equal to unity.

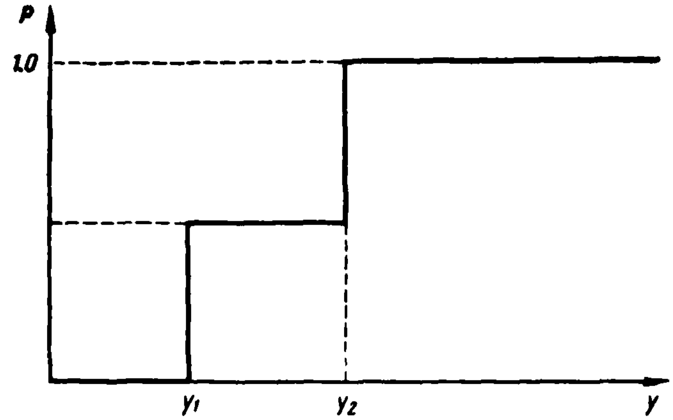


Figure 16. Distribution Function of a Discrete Random Variable.

Knowing the distribution function of a random variable, we can find the probability that it will fall into a given sector, which is equal to an increment of the distribution function in this sector.

Thus, according to figure 15, the probability of random variable y falling into the sector $y_i \leq y \leq y_n$ equals

$$P(y_i < y < y_n) = 1 - P_i. \qquad (22)$$

For continuous random variables we very often consider a derivative of the distribution function

$$p(y) = \frac{dP(y)}{dy}, \qquad (23)$$

called the distribution density of continuous random variable y. Sometimes function (23) is called a differential distribution function. A curve

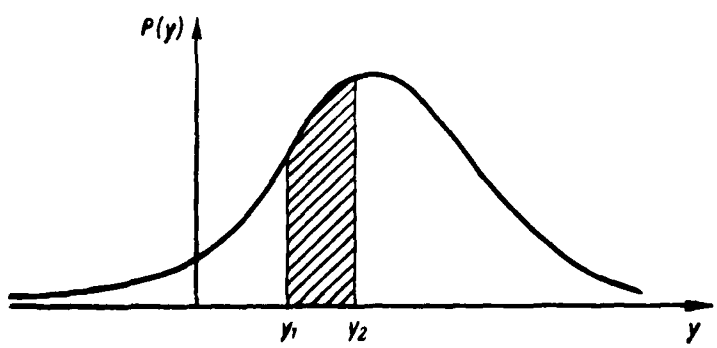


Figure 17. Distribution Curve.

showing the distribution density is called a distribution curve (figure 17). The probability of the random variable y falling in a certain sector equates to the area of the distribution curve lying on this sector

$$P(y_1 < y < y_2) = \int_{y_1}^{y_2} p(y)\,dy. \tag{24}$$

The probability of a particular event can be forecast in forecasting the distribution functions in question (distribution densities for continuous random variables). In this case, as we have already noted, it is possible to give an exhaustive forecast from the probabilistic point of view of a given random variable, the accuracy of which will depend on the accuracy of the forecast of the distribution function. However, in practice it is frequently unnecessary to characterize a random variable fully, and it is sometimes sufficient to forecast only certain numerical parameters which characterize essential features of distribution (the mean about which possible values of a random variable are grouped, the quantity which characterizes the dispersion of these values in relation to the mean, etc.).

In certain cases the data obtained from observations of the process being forecast can be described by standard distributions of continuous and discrete random variables. Among these the most widely used are normal, uniform, exponential, Poisson, and certain other distributions. If the form of the distribution law of the quantity being forecast is known a priori, it is sufficient to determine from the results of the observations only a small number of parameters for the distribution to be fully characterized. For example, for normal distribution, which is most often used in practice, such parameters are the expected value and the standard deviation. The problem of forecasting by means of probability models consists in determining from the probability distribution curve magnitudes of parameter y such that probability P_y is equal to the given (assumed) value of P, for example, $P = 0.95$.

In practice, observations of the process being forecast may result in an empirical distribution of the probability of the quantity being forecast which differs from known standard deviations. Generally speaking, this is unavoidable, since we cannot get rid of uncertainties associated with the random nature of statistical distribution. These uncertainties are a consequence of the limited number of observations (trials), and also of various kinds of interference which attend the process being forecast. Only if we conduct a very large number of observations (trials) will the elements of chance flatten out and the pattern inherent in the process being forecast become clearly visible. However, in practice the number of observations (trials) is, as a rule, limited and we have to resolve the question of selecting for the given empirical distribution a theoretical distribution curve which characterizes the regular features of the process being forecast.

In resolving the problem assigned it is first of all necessary to select the form of the theoretical distribution curve. The shape of this curve, like the form of the deterministic base of the analytical models considered above, is selected on the basis of an analysis of the nature of the process being forecast and, in some cases, simply in accordance with the form of the empirical distribution, although in the second case the selection of the form of the theoretical distribution based on the form of the empirical distribution should be approached very cautiously, on account of the random nature of the latter. Having selected the form of the theoretical distribution curve, we come to the problem of estimating its unknown parameters. The method of moments is often used for solving this problem. According to this, the unknown parameters of the theoretical distribution are selected proceeding from a condition of equality of several of the most important moments of the theoretical and empirical distributions. For example, if the theoretical distribution curve is a function of two parameters, these parameters are selected in such a manner that the expected value and variance of the theoretical distribution agrees with the estimates of the corresponding quantities of the empirical distribution. It should be noted, however, that the use of moments higher than the fourth order is impractical, since the accuracy of the calculation of moments decreases as their order increases. Readers interested in obtaining a more detailed understanding of problems relating to the determination of the theoretical distribution are referred to bibliography items [6], [11], and [15].

Having selected the theoretical distribution, we have, as a rule, to solve the problem of determining whether the discrepancies between the theoretical and empirical distributions (which will always occur) are random (for example, as a consequence of the limited number of trials) or whether they are the consequence of the fact that the form of theoretical distribution selected does not correspond to the actual distribution. To answer this question we can make use of so-called agreement criteria. Agreement criteria are based on the use of a certain quantity R, which characterizes the degree of discrepancy between the theoretical and empirical distributions. Such a quantity may be, for example, the sum of the squares of the deviations of the theoretical probabilities from the corresponding frequencies, or the maximum deviation of the theoretical distribution function $P_{th}(y)$ from the empirical distribution function $P_{em}(y)$. Obviously, by virtue of the random nature of the empirical distribution, R is a random quantity. Its distribution law depends on the distribution law of the random variable y and the number of observations (trials) N. Let us consider a hypothesis H that the distribution law of the random variable y is characterized by distribution function $P_{th}(y)$. If this hypothesis is true the distribution law of R is determined by the distribution law of y and the number N.

To solve the given problem on the assumption that hypothesis H is true, it is necessary to calculate the probability that the resulting empirical discrepancy r will not prove to be greater than discrepancy R, i.e., $r \leq R$. If this probability is sufficiently great, it should be recognized that the observation data do not contradict hypothesis H; otherwise the hypothesis can be rejected, i.e., the probability under consideration is one of the problems associated with the verification of the plausibility of hypotheses.

Obviously, the problem assigned can be solved if the distribution law of R is known.

In mathematical statistics use is made of several measures of discrepancy which possess simple properties and, where N are sufficiently large, do not depend on $P_{th}(y)$ for all practical purposes. We shall consider two of these.

A. N. Kolmogorov proposed an agreement criterion which uses as a measure of discrepancy the maximum value of the modulus of difference between $P_{th}(y)$ and $P_{em}(y)$:

$$R = \max |P_{em}(y) - P_{th}(y)|. \tag{25}$$

Regardless of the form of the distribution function of a continuous random variable y for an unlimited increase in N, the probability $P(\lambda)$ tends toward the limit

$$P(\lambda) = 1 - \sum_{k=-\infty}^{\infty} (-1)^k e^{-2k^2\lambda^2}, \tag{26}$$

where

$$\lambda < R\sqrt{N}.$$

By determining the maximum value of the modulus of difference R between the empirical and theoretical distribution functions and thereby determining the value of $\lambda = R\sqrt{N}$, we find $P(\lambda)$, which is the probability that the resulting actual discrepancy will not be greater than the maximum discrepancy between $P_{th}(y)$ and $P_{em}(y)$. With a large value of $P(\lambda)$ hypothesis H can be accepted; with a low value, it is rejected. Values of $P(\lambda)$ calculated from formula (26) are given in table 4.

Table 4.

λ	$P(\lambda)$	λ	$P(\lambda)$	λ	$P(\lambda)$
0.0	1.000	0.7	0.711	1.4	0.040
0.1	1.000	0.8	0.544	1.5	0.022
0.2	1.000	0.9	0.393	1.6	0.012
0.3	1.000	1.0	0.270	1.7	0.006
0.4	0.997	1.1	0.178	1.8	0.003
0.5	0.964	1.2	0.112	1.9	0.002
0.6	0.864	1.3	0.068	2.0	0.001

A. N. Kolmogorov's criterion is very convenient in practical work; however, it does presuppose that function $P_{th}(y)$ is known a priori. In cases where only the form of function $P_{th}(y)$ is known, while its parameters are unknown, the given problem can be solved by the use of Pearson's "χ^2 criterion." Here, as a measure of discrepancy, we take the quantity

$$r = \chi^2 = \sum_{i=1}^{n} \frac{(k_i - Np_i)^2}{Np_i}, \tag{27}$$

where

n = the number of intervals into which we divide the scale of the variable y which interests us;

k_i = the number of values of the random variable y in the ith interval;

p_i = the theoretical probability of the random variable y falling into the ith interval, calculated from the resultant theoretical distribution function.

The χ^2 distribution is tabulated for predetermined probability and number of degrees of freedom ρ [5]. The number of degrees of freedom ρ is equal to the number of intervals minus the number of limitations (relations) imposed on the frequencies

$$p_i^* = \frac{k_i}{N}.$$

One such limitation is

$$\sum_{i=1}^{n} p_i^* = 1. \tag{28}$$

Other limitations arising out of the use of the method of moments are

$$\hat{y} = \sum_{i=1}^{n} y_i p_i^* = M[y], \tag{29}$$

which characterize the requirements of equality of the empirical mean and the expected value of random variable y, and

$$\sum_{i=1}^{n} (y_i - \hat{y})^2 p_i^* = D(y), \tag{30}$$

if agreement of the empirical and theoretical variances, etc., is required.

Having determined from formula (27) the value of $r = \chi^2$ for the given series of observations (trials), by χ^2 and the number of degrees of freedom ρ from the table [5], we can determine the probability that the quantity distributed according to the χ^2 law will surpass the trial value

(27). In other words, guided by hypothesis H, we can determine the probability that the actual discrepancy between the theoretical and empirical distributions resulting from the trial will not be greater than is theoretically possible. The magnitude of this probability provides the basis for accepting or rejecting the hypothesis, as contradicting or not contradicting the trial data. It should be noted that it is expedient to use these criteria when the number of trials is sufficiently great (of the order of several hundred), since the criteria are based on a limiting distribution of the degree of discrepancy R for $N \to \infty$. In addition to this, it is essential that k_i should not be too small (5–10), otherwise the intervals should be combined.

In cases where, for any reason, it is not possible to reduce the empirical distribution to known theoretical distributions, the empirical distribution law can be used for forecasting purposes. However, it is essential to be sure that it correctly expresses the basic regularities of the process being forecast.

From the foregoing it follows that a probability model of a process to be forecast can be written in the following form, for example:

$$P_y = \bar{P}, \tag{31}$$

where $\bar{P} = (P_1, P_2, \ldots, P_n)$ probabilities P_{y_k}, which characterize the probability that the value of y will be less than or equal to y_k.

Let us consider some examples of how to determine the parameters of a theoretical probability distribution function and agreement of theoretical and empirical distributions.

Example 12. Table 5 and figure 18 show the results of processing data on relative errors $\frac{\delta y}{y} \cdot 1000$ in firing 400 rounds at coordinate y.

Table 5.

Error values	From −3 to −2	From −2 to −1	From −1 to −0	From 0 to 1	From 1 to 2	From 2 to 3
K_i	6	32	120	176	60	6
p^*_i	0.015	0.08	0.3	0.44	0.15	0.015
p_i	0.010	0.09	0.31	0.41	0.15	0.019
Np_i	4	36	124	164	60	7.6

It is necessary to determine the parameters of a theoretical distribution law, if it is to be considered normal.

From test data we determine the mean value and estimate the error variance:

$$\hat{y} = \sum_{i=1}^{6} y_i p_i^* = 0.175;$$

$$\hat{D}(y) = \sum_{i=1}^{6} y_i^2 p_i^* - (\hat{y})^2 = 0.87; \; (\check{\sigma}_y = D^{1/2}(y) = 0.93).$$

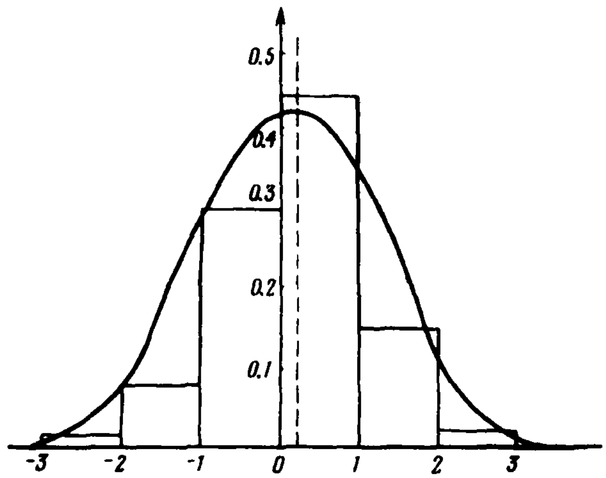


Figure 18. Example 12.

The value of the error in the middle of the ith interval is taken as y_i. Consequently, the corresponding normal law—the model of the firing errors—will have the form

$$p(y) = \frac{1}{0.93\sqrt{2\pi}} e^{-\frac{(y-0.175)^2}{2 \cdot 0.87}},$$

which is represented in figure 18 by a smooth curve.

Example 13. Under the conditions of the preceding example we shall verify the agreement of the theoretical and empirical distributions.

Since the parameters of the normal law were not known a priori and we determined them by means of the method of moments, we shall select Pearson's χ^2 criterion as the criterion of agreement. We shall calculate the theoretical probabilities p_i of random variable y falling within the accepted intervals by means of the expression

$$p_i = \Phi^*\left(\frac{y_{i+1} - \hat{y}}{\hat{\sigma}_y}\right) - \Phi^*\left(\frac{y_i - \hat{y}}{\hat{\sigma}_y}\right),$$

where y_{i+1}, y_i = the boundaries of the ith interval;
Φ^* = the tabulated normal distribution function [5].

The results of the calculations of quantities p_i and Np_i are given in table 5. The value of χ^2 = 2.78 is found in accordance with formula (27). Considering that in the given case the number of degrees of freedom

$$\rho = 6 - 3 = 3,$$

we find from the χ^2 tables [5] that the values nearest to $\chi^2 = 2.78$ for value $\rho = 3$ are

$$\chi^2 = 2.37; \quad P = 0.5;$$
$$\chi^2 = 3.66; \quad P = 0.3,$$

hence the approximate probability value for $\chi^2 = 2.78$ will be 0.43. Since this value is not small, we are justified in taking the normal distribution law as a model of the error distribution of the type of firing under consideration. This model, in particular, according to formula (31), can be written in the form

$$P_y = (0.010;\ 0.100;\ 0.410;\ 0.820;\ 0.97;\ 0.989),$$

where the indicated probabilities characterize the probability of the appearance of firing errors less than -2; -1; 0; 1; 2; 3, respectively.

We have considered a one-dimensional probability model, which enables us to solve a problem of forecasting the value of a continuous variable y according to a predetermined probability. However, in practice we also encounter multidimensional probability models, which relate a certain multidimensional quantity $\bar{y}$ to probabilities P_i.

Example 14. In gunnery the distribution of the point of explosion of a shell in space is sometimes assumed to be a normal three-dimensional one with the following distribution *density*:

$$p(\bar{y}) = p(x,\ y,\ z) = \frac{1}{\sigma_x \sigma_y \sigma_z (2\pi)^{3/2}} e^{\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)},$$

where x, y, z are the coordinates of the point of explosion in the selected rectangular system of coordinates.

Probability models of events determined by discrete quantities and, in particular, events with two possible outcomes (detected—not detected, hit—not hit) occupy an important place in military affairs. In many cases the respective probabilities change with the passage of time.

Example 15. Let P_r be the probability that an object is located in the coverage zone of an electronic reconnaissance installation;

P_{λ} = the probability of tuning the intercept receiver to the corresponding waveband;
t_1 = the length of time the target radiates;
t_2 = the time during which there are no signals from the target;
γ = the intensity of observation.

Then the model, which characterizes the probability of signal detection, has the form

$$P = P_x P_\lambda \frac{t_1}{t_1 + t_2}[1 - e^{-\gamma t}].$$

Similar models are dealt with in more detail in bibliography item [61].

A separate class of probability models, which make it possible to solve certain problems of the utilization and planning of complex systems, is considered in an independent branch of mathematics—queueing theory. Models of this class relate the nature of the flow of demands, the productivity of a channel handling the demands, and the number of channels capable of providing service. Using models based on queueing theory, it is possible to solve, for example, problems of forecasting the average number of aerial targets which may pass through the zone of a given air defense system, problems of forecasting the capacity of a technical servicing station for handling a specific type of equipment, etc.

Example 16. Let us consider a model of a queueing system with refusals described by Erlang equations:

$$\left.\begin{aligned}
\frac{dp_0(t)}{dt} &= -\lambda p_0(t) + \mu p_1(t); \\
&\cdots\cdots\cdots\cdots\cdots\cdots \\
\frac{dp_k(t)}{dt} &= \lambda p_{k-1}(t) - (\lambda + k\mu) p_k(t) + (k+1)\mu p_{k+1}(t); \\
&\cdots\cdots\cdots\cdots\cdots\cdots \\
\frac{dp_n(t)}{dt} &= \lambda p_{n-1}(t) - n\mu p_n(t),
\end{aligned}\right\}$$

where

n	= the number of channels of the system (for example, the channels of foreign models of air defense guidance stations);
$p_0(t), \ldots, p_k(t), \ldots, p_n(t)$	= probabilities that an incoming demand (enemy aircraft) at moment t finds 0, . . ., k, . . ., n channels engaged, respectively (will not be fired at);
λ	= the density of the flow of demands (the flow of aircraft per unit of time);
$\mu = \frac{1}{m_{t\,f}}$ ($m_{t\,f}$	= the average time of servicing a demand, the time taken to guide air defense facilities onto the target.

Integration of the indicated system of equations for initial conditions $p_0(0) = 1$; $p_1(0) = \ldots = p_n(0) = 0$ (at the initial moment all channels are free) gives the function $p_k(t)$ for any k, which characterizes the average load of the system over the course of time. Specifically, $p_n(t)$ characterizes the probability of a refusal (a demand arriving at moment t will find all channels engaged).

Queueing theory can be used for solving certain problems relating to the dynamics of troop combat operations [54].

A large amount of literature on queueing theory is now available (for example, items [16] and [45] in the bibliography), to which the reader is referred for further information.

Extensive use is made of probability models in the forecasting of combat operations. In particular, models of duel-type combat operations fall into this category. In these models the respective probabilities relating to the parameters of the system are described in the form of differential equations.

Example 17. Let side A have one combat unit (for example, a tank), which can hit a combat unit of side B with one shot with probability $P(t)$. This probability changes with time (for example, as a result of a change in the distance between the enemies). The probability of side B hitting side A's combat unit in one shot is $P_e(t)$. The rate of fire of the combat units is λ and λ_e respectively. The model which enables us to determine the probability of the survival of combat units A and B has the form

$$P_A(t) = 1 - \int_0^t \lambda_e P_e(\tau) \exp\{-\int_0^\tau [\lambda P(u) + \lambda_e P_e(u)]\, du\}\, d\tau;$$

$$P_B(t) = 1 - \int_0^t \lambda P(\tau) \exp\{-\int_0^\tau [\lambda P(u) + \lambda_e P_e(u)]\, du\}\, d\tau.$$

Knowing (or forecasting) quantities λ and $P(t)$, we can forecast the variations with time of the respective probabilities of the combat units under various combat conditions.

Readers wishing to obtain more detailed information about models of duel-type actions are referred to P. N. Tkachenko's book on mathematical models of combat operations [54].

Thus, as the above examples show, probability models have very wide applications in military forecasting.

6. Models Described by Differential Equations

In a good many cases it is not possible to express the quantity being forecast in terms of other quantities, and its description by means of the

probability models discussed above is inadequate from the point of view of forecasting problems. A model of a process to be forecast can be a differential equation or a system of differential equations (linear, nonlinear, partial, delayed arguments, etc.). Frequently the problem of forecasting the characteristics of processes described by such models cannot be resolved analytically.

Models of processes based on differential equations cannot, of course, be constructed on the results of past observations of the process being forecast. The construction of such models entails a thorough physical analysis of the phenomena which lead to changes in the process being forecast and requires special scientific research.

Differential equations as models are incomparably richer in content than, for example, models described by algebraic and transcendental equations. The advantage of the latter consists in their simplicity and comparative convenience in operation. However, differential equations permit a more detailed study of the dynamic process of the formation of the quantity being forecast, consideration of the influence of certain parameters of the model on the stability of the process being forecast, as well as the solution of the problem of selecting the magnitudes of the parameters of the process (if we are able to do this), so that the process being forecast will proceed in the required direction in the future. Thus, models based on differential equations greatly expand and enrich the problem of forecasting. It should be noted that the models considered above are particular solutions of the respective differential equations. However, they characterize the already established development of the process being forecast (which, by the way, for a number of forecasting purposes is quite adequate). The number and variety of processes which can be described by differential equations is so great that it would be impossible in the limited scope of this book even to enumerate them sufficiently completely. Therefore, we shall confine ourselves to several examples of models based on differential equations that are used in military affairs.

Example 18. The equations of the movement of the center of mass of an artillery shell in the air, as we know from the "External Ballistics" course, can be written in the following form:

$$\frac{d^2x}{dt^2} = -cH(y)\,G(v)\,\frac{dx}{dt};$$

$$\frac{d^2y}{dt^2} = -cH(y)\,G(v)\,\frac{dy}{dt} - g,$$

where

x, y = the coordinates of the shell's center of mass in a rectangular system of coordinates, related to a flat, nonrotating earth;
c = the ballistic coefficient;
$H(y)$ = the air density function under normal meteorological conditions, which depends on altitude;
$G(v)$ = the air resistance function;
g = gravity acceleration, assumed to be constant in magnitude and direction.

Even before modern computers were used for the solution of external ballistics equations, numerical integration methods had been developed. With the computers that are available today the integration of such equations to the required degree of accuracy presents no practical difficulties.

The development and production of guided ballistic missiles posed the problem of forecasting their trajectories. The problem was complicated by the fact that, in addition to equations of the movement of the missile as such, it was necessary to take into consideration equations of the control system and the controlling members. In addition to this, a number of assumptions made for artillery (a flat, nonrotating earth, constancy of gravity acceleration, etc.) are fundamentally unsuitable for guided missiles because of the enormous range and altitude of flight and the exacting requirements for accuracy in forecasting trajectory points. However, all these difficulties have been and are being successfully overcome by the solution of extremely complex systems of differential equations on modern high-speed computers. In both the Soviet and foreign literature there are numerous works dealing with various questions of the theory and design of guided ballistic missiles. Bibliography item [63], for example, is devoted specifically to the question of forecasting trajectories of ballistic missiles.

The increased requirements for accuracy of control under conditions influenced by random interference led to the origin of the theory of optimal forecasting filters, which is being successfully developed and which owes its existence to the work of A. N. Kolmogorov, N. Wiener, R. Kalman, L. Zadeh and other mathematicians. Works recommended to readers interested in acquiring further information about questions of optimal filtration and forecasting filters include bibliography items [25], [72], and [75].

Example 19. The theory of filtration and forecasting of transient random processes elaborated by R. Kalman forms the basis of the forecasting filter, which provides for the forecasting of the multidimensional random process $x(t)$, generated by a model of a linear dynamic system:

$$\frac{dx}{dt} = F(t)\,x(t) + G(t)\,u(t);$$

$$z(t) = H(t)\,x(t) + v(t).$$

where

$u(t)$ = the input signal;
$z(t)$ = observation data on random process $x(t)$;
$v(t)$ = interference;
$F(t)$ = matrix characterizing the dynamic properties of the system;
$G(t)$ = matrix characterizing the limitations on the input signal;
$H(t)$ = matrix characterizing limitations imposed on the feasibility of observations of the state of the system.

The optimal forecast of process $x(t)$ at moment of time $t+\Delta t$ (Δt is the lead interval) is determined from the expression

$$\hat{x}(t+\Delta t) = \Phi(t+\Delta t, t)\,\hat{x}(t),$$

where $\Phi(t+\Delta t, t)$ is a transition matrix of a system which satisfies the differential equation

$$\frac{d\Phi}{dt} = F(t)\,\Phi,$$

$\hat{x}(t)$ is the optimal estimate of the process being forecast at the present moment of time, determined from the expression

$$\frac{d\hat{x}(t)}{dt} = F(t)\,\hat{x}(t) + K(t)\left[z(t) - H(t)\,\hat{x}(t)\right],$$

where $K(t)$ is the matrix amplification coefficient, determined in relation to the dynamic properties of the system, the limitations imposed upon observations of the process being forecast, and the interference characteristics.

For more detailed information about Kalman's filter theory, the reader is referred to bibliography item [72].

By using a model of a forecasting filter one can investigate the characteristics of a future process under laboratory conditions (for determining, for example, the optimal characteristics of a projected system of controlling a dynamic object), and also forecast directly the realization of a current actual process for the purpose of adopting necessary measures for the optimal behavior (for example, of the control of a dynamic object) in a given concrete situation.

Finally, let us consider the use of models of combat operations described by differential equations. The probability models considered above are very convenient for description, if the number of possible states of the system is comparatively small. If the number of possible states increases (to several dozen or more), the use of these models becomes inconvenient on account of the large volume of calculations and the

excessive amount of work that this entails, and also because of the difficulty of reviewing and comprehending the results obtained. Therefore, the dynamics of averages method is used for forecasting such processes. This method involves direct study of the average characteristics of random processes taking place in complex systems with a large number of states. It makes it possible to work out and solve equations directly for the average characteristics that interest us, bypassing the probabilities of the states; the basis for using this method is the great complexity of the processes being studied and the large number of elements which they involve, i.e., precisely the reasons which make it difficult to study such processes by other more detailed methods.

The dynamics of averages method is used with success for describing combat actions involving the participation of large groups of elements of one kind or another. It should be noted that this method was actually developed in response to the need to study military questions. Differential equations which describe the variation in the numerical strength of the opposing sides in the course of a battle appeared on the scene in World War I and are now known in the literature as "Lanchester's equations," although they had been put forward by Osipov earlier.

Example 20. Let us assume that the original number of combat units on one side is n_0, the present number n, and that each of them with probability P hits an enemy combat unit with every shot, the rate of fire being λ.

All the units on one side are identical. The enemy has: n_{0e}, n_e, P_e, and λ_e, respectively. Let us assume that the battle is fully regulated, i.e., all the combat units have been reconnoitered and only units not yet hit are fired on. We can then assume that the rate of loss on one side is proportional to the product of the number of combat units on the other side and the rate of fire and hit probability:

$$\frac{dn(t)}{dt} = -n_e(t) P_e \lambda_e;$$

$$\frac{dn_e(t)}{dt} = -n(t) P\lambda.$$

The solution of these differential equations will enable us to determine the number of intact units on each side at any moment of time. It should be noted that in equations of combat dynamics it is possible to consider various factors relating to the organization of combat operations, such as

—the commitment of reserves;
—preemptive attack by one side;
—exhaustion of ammunition on hand;
—the presence of different types of combat units, etc.

We can show that the parameters which determine victory for one side or the other, using the cited equations, are

$$\Phi = P\lambda n_0^2 \text{ and } \Phi_e = P_e \lambda_e n_{0e}^2,$$

i.e., victory goes to the side which has the greater Φ, in other words, the greater product of the probability of hitting a combat unit by the rate of fire and the square of the original number of combat units. This result makes common sense. However, as follows from the expressions for Φ, the initial number of combat units has the greatest influence on the outcome of the battle, since it is squared. It is emphasized once again that the results obtained are true "on the average," i.e., the result $\Phi>\Phi_e$ still does not imply that in some specific battle, in which the same quantities P, λ, and n_0 apply, victory would be impossible for the second side. More detailed information about battle models in the form of Lanchester equations can be obtained from bibliography items [12], [54], and [61].

The battle models under consideration were developed a stage further with the appearance of space-time models, which make it possible to study the occurrence of combat operations, not only in time, but in space, thus permitting troop combat formations to be selected on a rational basis [61].

Example 21. Let us assume that there are two multiple groupings, of resources of the same type, elements of which are characterized by

—density ρ and ρ_e, i.e., the number of combat units per unit of area;
—the rate of movement of the front line with components u and v;
—combat effectiveness and vulnerability indices, which determine the rate of loss on both sides; $f(\rho, \rho_e)$ and $f_e(\rho, \rho_e)$.

For the case in question the following differential equations of the movement of the front line can be written:

$$\frac{\partial\rho}{\partial t} + u\frac{\partial\rho}{\partial x} + v\frac{\partial\rho}{\partial y} + \rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -f_e(\rho, \rho_e);$$

$$\frac{\partial\rho_e}{\partial t} + u\frac{\partial\rho_e}{\partial x} + v\frac{\partial\rho_e}{\partial y} + \rho_e\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -f(\rho, \rho_e);$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -F_x - \eta;$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -F_y - \xi,$$

where F_x and F_y are functions analogous to the forces of resistance to movement, which can be expressed as follows:

$$F = v_{max}\frac{4\frac{\rho}{\rho_e}\cdot\frac{d}{dt}\left(\frac{\rho}{\rho_e}\right)}{\left[\left(\frac{\rho}{\rho_e}\right)^2 + 1\right]^2},$$

where v_{max} is the maximum possible rate of movement of forces in the course of combat operations.

The solution of the given system of equations makes it possible to determine the movement of the forces in space and time, with fixed control, i.e., for predetermined η, ξ and initial conditions

$$\left(\frac{\partial\rho}{\partial x}\right)_0, \left(\frac{\partial\rho}{\partial y}\right)_0, \left(\frac{\partial\rho_e}{\partial x}\right)_0, \left(\frac{\partial\rho_e}{\partial y}\right)_0, \left(\frac{\partial u}{\partial x}\right)_0, \left(\frac{\partial v}{\partial x}\right)_0, \ldots,$$

and it also enables us to select the optimal control.

Thus, use of these and similar models with predetermined initial conditions and predetermined variation of certain parameters of these models in the process of solution makes it possible to forecast the course and outcome of the combat operations in question. If this forecast is unfavorable, it will be necessary to take the appropriate measures (change the initial correlation of forces, the tactics of employment of certain weapons, the plan for bringing up the reserves, etc.) so that the future real combat operations proceed in the required direction.

7. Statistical Trials Models

Statistical trials models occupy an important place in forecasting the results of combat operations. The essence of the statistical trials method consists in reproducing the realization of the random process to be forecast on a computer (as a rule, a digital computer) by a special algorithm. In addition to this, all the probable regularities of various random factors influencing the process being forecast are taken into account. Generally speaking, these are quite numerous. The outcome of each individual realization is, of course, random. However, on modern electronic digital computers it is possible to obtain within comparatively short periods of time a large number of realizations of the process being forecast, the processing of which permits statistical estimates to be made of the values of the parameters of the process being forecast. These estimates are now stable, since they were obtained from the results of a sufficiently large number of trials. This is a consequence of the law of large numbers, which forms the theoretical basis for the statistical trials method. According to this law, with an unlimited number of independent trials, the arithmetic mean of the observed values of a random variable with a finite variance, converges in probability to its expected value, which is a nonrandom variable. Another manifestation of the law of large numbers consists in the fact that with an unlimited increase in the number of independent trials under invariable conditions the frequency of the event in question converges in probability to its probability.

The virtue of the statistical trials model is that it can be used for practically any problem with random outcomes and enables us to obtain the required degree of accuracy (given the necessary number of trials). Its disadvantages are that it entails a considerable amount of work and that it is not possible in each realization to estimate the influence of certain factors on the result of the investigations, which necessitates carrying out a large number of calculations.

A battle as a finite process with a random outcome can be described mathematically as follows.

The quantitative and qualitative composition of two opposing sides A and B can be characterized by two finite sets U and V of parameters $u_1, u_2, \ldots, u_m$ and $v_1, v_2, \ldots, v_n$ [54]:

$$U = \{u_1,\ u_2,\ \ldots,\ u_m\} = \{u_i\},\quad i = 1,\ 2,\ \ldots,\ m;$$
$$V = \{v_1,\ v_2,\ \ldots,\ v_n\} = \{v_j\},\quad j = 1,\ 2,\ \ldots,\ n.$$

For each element of these sets there is a multiple random function which determines the state of this element at any moment of time t which is found in the range $T_{\text{beg}} \leq t \leq T_{\text{end}}$, where T_{beg} and T_{end} are the times of the beginning and end of the battle, respectively. Thus, for example, for the element

$$u_i \in U\,(i = 1,\ 2,\ \ldots,\ m)$$

there is the function

$$\bar{\xi}_i(t) = [\xi_{i1}(t),\ \xi_{i2}(t),\ \ldots,\ \xi_{ip}(t)],$$

the components of which are called parameters of element u_i. In the given trial there is an l-realization of random function $\bar{\xi}_i(t)$:

$$\bar{\xi}_i^l(t) = [\xi_{i1}^l(t),\ \xi_{i2}^l(t),\ \ldots,\ \xi_{ip}^l(t)],$$

the value of which at moment of time $T_{\text{beg}} \leq t_{\text{K}} \leq T_{\text{end}}$ determines the state of element u_i at moment of time t_{K} in l-realization of the process of the battle:

$$\bar{\xi}_i^l(t_k) = [\xi_{i1}^l(t_{\text{к}}),\ \xi_{i2}^l(t_{\text{к}}),\ \ldots,\ \xi_{ip}^l(t_{\text{к}})].*$$

The aggregate of $\{\bar{\xi}_i^l(t_{\text{K}})\}$ for all $i = 1, 2, \ldots, m$ determines the state of side A at moment of time t_{K} in the l-realization of the battle. Correspondingly, $\{\bar{\xi}_i^l(T_{\text{beg}})\}$ and $\{\bar{\xi}_i^l(T_{\text{end}})\}$ for all $i = 1, 2, \ldots, m$ determine the state of side A at the beginning and end of the l-battle.

*[The reader will note here and on pages 145 and 208–212 a problem which neither the translator nor the editor has been able to solve. The small $_{\text{к}}$ that is identical in form to a capital $_{\text{K}}$ is the Cyrillic lower case K, which the reader will note is formed differently from the Latin lower case k. It is the practice in this book to use Latin characters for abstract symbols, reserving Cyrillic letters for abbreviations of Russian words. However, no Russian word in the text beginning with a K stands out as being the one in question. Given the lower case Latin k in the first form on this line, it is difficult to determine whether it was that one or the Cyrillic K's which were actually intended or if exactly what was set was intended. All such forms have been left exactly as they appeared in the original so as not to force the decision for the reader—U.S. Ed.]

The state and elements of side B can be described in exactly the same way.

If the state of side B at the present moment of time for the l-realization is denoted by $\{\bar{\varepsilon}_j^l(t)\}$ ($j = 1, 2, \ldots, n$), the initial state of the l-battle will be the aggregate of:

$$\{\bar{\xi}_i^l(T_{\text{beg}})\},\ i = 1,\ 2,\ \ldots,\ m;$$
$$\{\bar{\varepsilon}_j^l(T_{\text{beg}})\},\ j = 1,\ 2,\ \ldots,\ n,$$

while the ultimate state of the battle will be characterized by the aggregate of:

$$\{\bar{\xi}_i^l(T_{\text{end}})\},\ i = 1,\ 2,\ \ldots,\ m;$$
$$\{\bar{\varepsilon}_j^l(T_{\text{end}})\},\ j = 1,\ 2,\ \ldots,\ n.$$

If certain functionals are given

$$F_r\,[\{\bar{\xi}_i^l(T_{\text{end}})\},\ \{\bar{\varepsilon}_j^l(T_{\text{end}})\}],$$
$$r = 1,\ 2,\ \ldots,\ R,$$

which determine the criteria for evaluating the battle, the values of these functionals for concrete values of arguments for the l-battle determine the outcome of the battle with respect to the relevant criterion.

As we have already said, given the required number of realizations (computer runs of the required number of battles) for given U and V we are able to forecast the result of a future battle under similar conditions and with corresponding composition of the opposing sides.

Since a mathematical model of statistical trials is an algorithm, realized on a computer, we shall give as an example, a model of the repulse of a tank attack.

Example 22. Antitank weapons and tanks are positioned on predetermined lines. The tanks move towards the line defended by the antitank weapons. When the tanks come within range of effective fire (allowing for the tactics and processes of detection), certain of the antitank weapons open fire on the enemy. After each shot the event is determined: was the target hit or not? If a tank was hit, the targets are redistributed. From the moment the antitank weapons open fire, the tanks, in turn, begin to detect them and open fire. For every shot the event is determined: was an antitank weapon hit, or not? If it was hit, the targets are redistributed.

Let us consider the parameters introduced into the model. To each antitank weapon we shall assign index i; for each tank, index j; and for each moment of time, index k.

The characteristics of the antitank weapon are:

—the probability of hitting a given tank with one shot;
—rate of fire;

—the probability of detecting the tank in direct visibility conditions;
—the probability of detection of the antitank weapon by the tanks;
—the pattern of damage inflicted on the antitank weapon.

The characteristics of the tanks and their armament:
—thickness of armor plating, which determines the pattern of damage by the antitank weapons;
—speed;
—overall dimensions of the tank, which determine the probability of detection and, together with its speed, the probability of being hit;
—the probability of hitting the antitank weapons;
—the probability of detecting the antitank weapons;
—rate of fire.

It should be noted that some of the indicated characteristics (for example, the probability of detection of tanks and antitank weapons, the probability of a hit, etc.), which are input data in a model of statistical trials, can be worked out with other forecasting models (for example, the probability models considered above). This once again confirms the fact that a forecast of combat operations is a very complex research process based on the use of an extremely wide variety of the forecasting models described above.

The most important parameters of antitank weapon tactics in modeling are:
—range of opening fire, which we can assume to be less than or equal to the range of effective fire;
—order of target selection.

The order of target selection is determined by the fact that an antitank weapon fires if and when a tank comes into the sector allocated to it. However, several tanks may come into this sector. As a rule, antitank weapon sectors overlap, in which case it is necessary to select a system of logical rules, which ensures uniform coverage of all targets and excludes the possibility of one and the same tank being engaged by several weapons, while other tanks in the sector are unopposed.

The most important parameters of tank tactics which should be taken into consideration in modeling are:
—selection of the type of weapon (cannon, machine gun, etc.) used to engage a particular target, which is governed by the efficiency ratio of these types of weapons under the given conditions;
—the order of target selection (in addition to what has been said about the selection of targets for antitank weapons, it is also necessary to consider the importance of the targets);
—choice of the method of firing (on the move or during brief halts).

The disposition of the antitank weapons, determined by their coordinates, can be fixed by experts in their tactical employment; it can also be random. The same applies to the disposition of the tanks. The model of the battle is subdivided into a series of units, which fulfill specific functions:
—coordinates;
—visibility;
—dectection;
—target distribution;
—firing;
—evaluation of the results of the battle;
—evaluation of the accuracy of the results;
—obtaining random numbers according to various distribution laws;
—time.

In the coordinate unit the coordinates of the tanks are determined at given moments of time. Allowing for the nature of the terrain, the position of the tanks is determined, with a consideration of the probability that they will move into an adjacent sector. The time of the movement of a tank from one sector to another is defined as the quotient of the division of the length of this movement by the average speed in this sector.

The possibility of direct visibility from one point to another is determined in the visibility unit.

In the detection unit the probability of detection, which is used as the basis for deciding whether a given weapon has been detected by another weapon or not, is calculated from a predetermined formulary relationship between the probability of detection and the relevant parameters. An important factor determining the probability of detection is the firing of a weapon. Consequently, information about which weapons were fired goes into this unit. Of course, the question of detection is considered only for weapons which are directly visible. Therefore, information from the visibility unit also goes into this unit.

The distribution of fire among weapons is assigned in the target distribution unit. First, for each weapon targets are allocated which:

—are located in the sector assigned to the weapon;

—have been detected by the given weapon;

—are within range of opening fire.

Should there be more than one such target, a selection is made according to predetermined rules. For example, the first target fired upon is that which is located in the center of the sector, or closest to the weapon, or the most dangerous target, i.e., the one whose fire is the most effective.

At the start of each new cycle it is necessary to add to the target list of the preceding cycle newly detected targets and delete from it those which have been destroyed and those which are concealed.

In the firing unit the probability of hitting a target with a shot and the answer to the question of whether or not a target has been hit are found from a formulary relationship or a table.

In the unit for obtaining random numbers according to distribution laws introduced a priori, random numbers are produced which are used in determining the state of a particular probabilistic element. For example, if the probability of hitting a tank with a given antitank weapon with one shot is *P*, while the random number obtained, for example, from a random number generator, is less than *P*, the tank is assumed to have been hit, otherwise it is presumed to be intact.

The time unit ensures the accurate determination in time of the combat operations being conducted. Two clocks are provided for each weapon: one controls the firing; the other, the movements from one sector to another. These clocks show the time at which the weapon associated with it should begin to move, fire, or select a target. The time the tanks are located in each sector is taken from the tank movement clock; the time between shots, determined on the basis of the weapon's rate of fire and its unit of fire, is taken from the firing clock.

In order to select the next weapon, the machine checks all the cells (clocks), recognizes the cell registering the earliest time and begins the next cycle, which includes an analysis of the current situation of each weapon, the performance of a specific operation, and resetting of the clocks.

On completion of each realization (an indication of which might be, for example, the destruction of all the tanks or, on the other hand, the fact that they reached the forward edge) the selected criteria are calculated and the results obtained during all of the conducted trials are computed in the battle results unit. Finally, the estimates of the expected values of the criteria and the characteristics of their accuracy are computed (in the unit for estimating the accuracy of the results). When the required accuracy characteristics have been obtained, the trials for the given variant are discontinued and the investigation of another variant is begun.

Thus, the use of statistical trials models, the extraction and processing of the results of the necessary number of realizations makes it possible to produce a forecast of the course and outcome of any combat operations and to introduce where necessary the required corrections to the qualitative and quantitative composition, the tactics of the use of our weapons and other parameters and characteristics in order to ensure the desired course and outcome of future combat operations under actual conditions.

NOTES

1. Lenin, XVIII, 306.
2. The concept "probability" is used here to emphasize the fact that the model directly characterizes the probability of a certain event, although, essentially, all models of stochastic processes are probabilistic.
3. This term is used in the foreign literature—Author's note.

Chapter 5. Existing Forecasting Methods

1. General Observations

The literature available today contains descriptions of numerous and varied forecasting systems, methods and procedures (see, for example, bibliography item [67]). However, they are all based in some way or another on the use of a heuristic or mathematical approach, or a combination of both of them.

The heuristic method of forecasting is based on the use of experts' predictions (forecasts) in a given field of knowledge. For example, military experts can predict potential targets at which the enemy will strike, even before he takes any concrete action (opening up with artillery fire, launching ballistic missiles, etc.). Mathematical forecasting models, depending on the type of models of the objects to be forecast and the means employed to compute unknown parameters of the models and values of the quantity being forecast at a future moment of time, are frequently divided into two major groups:

—methods of modeling processes (movement, development);
—methods of extrapolating available information about a process (statistics), often called statistical methods.

As with the classification of forecasting models, this differentiation is also to some extent arbitrary. Actually, on the one hand, in forecasting with models, we are essentially extrapolating (extending into the future) the resultant data. On the other hand, the statistical trials method, which we are fully justified in calling the statistical method, is a method of modeling the process under investigation. However, the above classification is sufficiently well established in the literature, and in the main we shall adhere to it.

The most typical example of mathematical modeling is the use of computers for the solution of differential equations of the movement of a ballistic missile for forecasting its point of fall and the dispersion characteristics for various initial conditions and various disturbances which occur on its trajectory.

Statistical methods consist in the use of statistical data relating to the object (process) being forecast to establish its deterministic base and compute its value for a predetermined moment of time (for given values of some other independent variables). The mathematical device most frequently used for determining unknown parameters of a model in statistical forecasting is the maximum likelihood method, specifically that version of it known as the least squares method.

The logical analysis of forecasting data and results is a very important factor. Logical analysis implies the study and interpretation of trends in the development of the object being forecast, analysis of the results of forecasting similar objects, and the estimation of the concrete results obtained in forecasting. In some cases logical analysis makes it possible to establish the fact that the mathematical model adopted for forecasting does not conform to the real object and in this sense serves as feedback in the overall system of forecasting. Logical analysis also occupies an important place in the final stage of the complex of investigations associated with forecasting. For example, forecasting provides coordinates of the point of fall of a ballistic missile slightly to one side of an important military target. Taking into account the importance of this object to the enemy, it may be considered feasible to maneuver the missile so that its point of fall coincides with this object. Apart from such considerations, logical analysis enables us to resolve a number of independent problems:

—the structure and analysis of the target tree which will be described in chapter 8;

—ascertaining the possibility and time of appearance of abrupt changes in the development of a process;

—establishing the correspondence and interrelationship of phenomena being studied by various branches of science;

—the structure of morphological models which serve as a basis for the construction of formalized forecasting models.

Morphological analysis, which provides the structure of morphological models, is based on the study of the structure of problems and comprehension of ways of solving them.

We shall discuss briefly the enumerated methods of forecasting.

2. The Heuristic Method of Forecasting

Heuristic forecasting is the oldest method being widely used in daily life, as well as in science, technology, and military affairs. This method is based on the generalization and statistical processing of opinions regarding future events put forward by highly qualified specialists in a particular field of knowledge. These specialists are, more often than not,

experts in their field, who, relying on their experience, knowledge, and available data, pronounce judgment on the probability of this or that event coming to pass in the future, the conditions and times of its occurrence, the sequence of future events, and their quantitative and qualitative expression. Although these expert judgments are subjected to mathematical processing in order to obtain a generalized opinion (since usually several experts are involved), the experts themselves do not as a rule use mathematical models in forecasting. An undoubted virtue of the heuristic method of forecasting is that its use enables us to avoid gross errors, especially in connection with abrupt changes of the quantity being forecast. In a number of cases, however, this method is difficult to put into practice. Heuristic elements of forecasting are used in military affairs in such phases as:

—assessment of the combat situation;
—calculation of the tactics of the operations of one's own and the enemy's forces;
—forecasting the enemy's intentions (concrete plans);
—discussion of the operation plan;
—adopting a decision on a particular concrete plan of operations.

The process of heuristic forecasting applied to characteristics of technical devices, for example, can be arbitrarily divided into a number of phases, chief of which are the following.

First, the phase of elaborating a forecast of the development of the natural sciences (this is used for a synopsis of the status of developments which may be accomplished in fixed periods of time); secondly, the phase of elaborating a forecast by technical experts, who, after studying a forecast, project possible characteristics of a given technical device which may be achieved in the indicated fixed periods; and thirdly, the phase of processing the results obtained by different experts independently. Although methods of obtaining information from experts vary quite widely, they can, nevertheless, be divided into two main groups: the "brainstorming"* method and questionnaire survey (when time permits).

The "brainstorming" method was practiced in the 1950's in studies carried out by the American RAND Corporation as a means of systematically evolving new ideas for the solution of problems of foreign policy and strategy. There are three types of "brainstorming": "direct brainstorming," "the group consensus" method, and the "operational creativity" method.

*[No attempt has been made to determine whether these are the actual words of the original terminology in English—U.S. Ed.]

The "direct brainstorming" is based on the hypothesis that a large number of ideas put forward by experts contains at least a few good ones. The method is as follows. A panel of experts is given a problem which has several possible solutions. Their ideas on the problem are pooled and then processed in several stages, the most promising ones being retained and the obviously incompletely developed ones rejected.

The "group consensus" method is based on the application of "brainstorming" aimed at establishing agreement and unity of views on a particular question. As a rule, six people participate in this process. This is the number of experts considered optimal from the point of view of success in achieving agreement on the basis of the experience of scientific research and experimental design work. It has been established that a larger number of experts complicates the process and results in a sharp increase in the time taken to achieve a consensus without increasing significantly the number of ideas put forward. With a smaller panel a number of factors might not be taken into consideration and the accuracy of the forecast would suffer as a result.

The "operational creativity" method assumes that the nature of the problem as a whole and the possible approaches to its solution are known only to the project or theme leader, who questions experts in order to confirm the correctness of his approach to the solution of the problem and to derive therefrom confidence in the project.

The "brainstorming" can be applied in military affairs, in drawing up the draft plans of military operations, for example.

Questionnaire surveying is a method of obtaining expert assessments by means of questionnaires. The questionnaires may be sets of questions to which the experts are asked to give clear-cut answers about the future state of the object of the forecast. A questionnaire may also contain an exposition of the conjectured future picture of certain events, and the expert is simply required to confirm or reject it. It may contain a request to estimate a future value of the quantity being forecast or the range in which such a value may fall at a specific moment of time in the future.

The general requirement of questionnaires is precision and clarity in the formulation of the problem and the exclusion of ambiguous comment. The questionnaire survey method can be used, for example, in resolving military-technical and military-economic forecasting problems.

Example 23. As an example of the heuristic method of forecasting we shall consider the so-called Delphi method. This method was devised in 1963–64 by research workers at the American RAND Corporation for studying and forecasting a number of important military problems.

Six broad spheres of forecasting were selected:

—major scientific discoveries;
—population growth;
—the automation of human activities;
—prospects of conquering space;
—the probability of the prevention of war;
—future armament plans.

For each sphere of forecasting an 82-member commission was set up. Commission members were questioned in four rounds by means of specially compiled questionnaires. The questions were formulated so that the answers to them required some kind of quantitative description. After each round all the experts were informed of the results of the survey.

In the first round each of the participants had to enumerate all the probable technical developments which could influence the event being forecast to a marked degree. The following factors were considered:

a) the desirability of the event (necessary, desirable, undesirable);

b) the feasibility of the event, reflecting both the technical feasibility and the possible complexity of developments (realization is a simple matter, probable, improbable but possible);

c) the time it would take for the realization of the event being forecast with an estimate of the date of the probable ($p = 0.05$) accomplishment of a particular technical development and the degree of accuracy of this estimate.

In the second round the experts assessed the conjectural technical development from the point of view of the same factors (desirability, feasibility, and date of accomplishment).

In the third round the deviations beyond the probability range 0.1–0.9 were eliminated from the experts' estimates of the time it would take to realize a particular forecast event by discussing these estimates individually with each expert.

In the fourth round the events were jointly evaluated by all the participating experts.

Thus, as round succeeded round, the experts' opinions on the given questions were refined and drawn together. Where individual forecasts deviated from the opinion of the majority the experts were asked to substantiate their points of view. The results of the questionnaires were processed statistically and used as a basis for forming generalizing characteristics expressing the achieved consensus of opinion.

Heuristic forecasting occupies an important place in the "Pattern" system designed in 1963–1964 by the American firm, Honeywell. The system was worked out in the interests of developing methods which, on the basis of a large quantity of information in the field of military production, would permit optimal national decisions to be adopted concerning the development of new weapons and the allocation of credits for their production in the period of time covered by the forecast (10–15 years). More detailed information about the "Pattern" system is given in bibliography items [33] and [49].

3. Mathematical Methods of Forecasting

In heuristic forecasting the opinion (forecast) of each expert is subjective. This circumstance gave rise to the use of mathematical methods of forecasting, the principal advantage of which is the objectivity of the resulting information and its high degree of accuracy (if the correct models are selected); in addition to which, with modern computers, we are able to mechanize the process of computing forecasts.

The principal phases of mathematical forecasting are:

—the selection and substantiation of the model of the process being forecast;

—the calculation (determination) by means of the model of the characteristics of the process or phenomenon being forecast for a predetermined moment of time in the future;

—analysis of the forecasting results and estimation of their accuracy.

The main assumption in mathematical forecasting is that the model of the process selected for the sector of observation remains unchanged, even at the moment of time for which the forecast is being made. In other words, it is assumed that the process being forecast will develop in accordance with the same laws as it did in the past and is doing at present.

As we have already mentioned, mathematical models of forecasting can be divided by convention into two broad groups: modeling methods and extrapolation methods (statistical methods). In connection with the physical models, widely used in military forecasting, we shall consider these as an independent method of forecasting—the physical modeling method (exercises, tests of actual models of weapons and military equipment, etc.). Thus, modeling as a method of forecasting in military affairs is subdivided into physical and mathematical modeling, depending on the conformity of the physical nature of the model to the real process being described.

In mathematical modeling the most widely used models are those based on differential equations, probability models, and models of statistical trials, which employ the Monte Carlo method.

The main feature of the mathematical modeling method that distinguishes it as an independent method is that it provides for obtaining an artificial **realization of the process being forecast,** from which it is possible to judge the behavior of the process being forecast in the future. In some cases we shall refer to this as an independent realization of a random process (the Monte Carlo method, an independent "battle" between two

subunits in exercises, computer modeling of the flight of a ballistic missile attended by random effects, etc.), and in other cases we shall attach to this realization a certain generalized significance (models of the dynamics of averages, stochastic duels, computer modeling of the flight of a ballistic missile with the random effects being allowed for by certain "average" values, etc.). Obviously, in the first case, to obtain data on the future with the required degree of accuracy we must have a sufficiently large number of such realizations so that, after the appropriate processing, we shall be able to obtain certain generalized data, which will characterize the process in question as a whole. In the second case, the derivation of generalized data in the process is ensured by the fact that data already possessing a generalized significance are included in the model (the relevant probabilities in equations of the dynamics of averages and in probability models, "average" values of disturbances in modeling the flight of a ballistic missile, etc.).

Forecasting with models consists in applying the generalized data obtained as a result of modeling to a future situation.

For example, wind-tunnel tests of an aircraft model have shown that its design has certain characteristics which will ensure the required flying mode. Using average dynamics equations we are able to conclude that side *A*, having a given number of tanks with given characteristics, should in a future battle beat side *B*, if the latter has so many tanks with such and such characteristics. A given air defense system will ensure the servicing (destruction) of such and such a number of targets with given characteristics in given raid conditions. The dispersion of a given type of ballistic missile, under various external conditions and types of disturbance, when fired over a predetermined distance, will possess certain characteristics.

Forecasting methods involving the extrapolation of statistics (statistical methods) possess the distinctive feature that forecasting is achieved by the **extrapolation of the current actual realization** of the process being forecast. For example, we are observing the flight (recording the coordinates) of a certain aircraft and we are interested in obtaining a forecast of the coordinates of this aircraft, say, ten seconds hence. Or, we have information about the cost of a certain article for the previous several years and we want to know what its cost will be during the next three years.

In this case we should obviously select a model that characterizes the variation of the given object in time, determine the unknown parameters of this model based on presently available information, and determine the value of the model at the required future moment in time.

Obviously, physical models cannot be used in extrapolation, since we are working directly with the object being forecast. Most widely used in statistical forecasting are models based on algebraic equations which relate the target quantity to time and a number of other quantities, the target quantity, as a rule, being clearly expressed in terms of other parameters and time.

Unlike modeling in which the form of the model and all its parameters are known (predetermined), in statistical forecasting not only are some parameters unknown a priori, but in certain cases the form of the model of the process as well. Even the elaboration (selection) of the form of the model of the process being forecast can be a complicated research problem, owing to the difficulty of gaining an insight into the nature of this process.

In statistical forecasting, because as a rule we are dealing with random processes, despite the fact that we have at our disposal a concrete (up to the moment) realization of the process being forecast, we project the future "average" value of the process (its deterministic base) and the region into which with a predetermined probability the actual realization of the process will fall in the future. Consequently, in this case, as in forecasting by modeling, we obtain certain generalized characteristics of the process being forecast in the future. This, as we have already pointed out, is quite natural, and is due to the presence of uncertainties which accompany the process being forecast, both in the past and in the present and future.

Mathematical forecasting will be considered in greater detail in chapter 7. In the same chapter we shall also examine a number of questions relating to problems of the mathematical forecasting of abrupt changes.

4. Combined Methods of Forecasting

Heuristic and mathematical methods of forecasting possess a number of merits and defects. Some of the qualities of these methods are compared in table 6.

Table 6.

Quality / Method	Objectivity	Calculation of abrupt changes	Feasibility of dispensing with a model	Simplicity of realization	Degree of elaboration
Heuristic	−	+	+	−	+
Mathematical	+	− (+)	−	+	+

As follows from an analysis of this table, the principal merits of these methods of forecasting complement each other quite well. Therefore, it

is quite natural that we should try to create a composite method which combines the merits of heuristic and mathematical forecasting and excludes their defects. The following example demonstrates one way of producing a combined forecast in the general case.

The process being forecast is analyzed, the principal factors affecting the variation of the quantity being forecast are ascertained, and a model of the process is built up. Of course, it may happen that certain parameters of the model cannot be determined from the analysis. In this case they can be estimated by statistical methods based on analysis and processing of statistics regarding the progress of the process in the observation sector.

After computing the estimates of the unknown parameters of the model, a mathematical forecast is made.

A heuristic forecast is made independently of the mathematical forecast (by individuals who did not participate in the elaboration of the mathematical forecast). The data provided by the mathematical and heuristic forecasts are compared so as to ascertain their "contradictoriness" or "noncontradictoriness." This is done by a mathematical method which will be discussed in the chapter dealing with combined forecasting. If the forecasts are "noncontradictory," they are processed jointly (see chapter 8) and the forecasting problem is considered solved. If they are "contradictory," the assumptions and conjectures forming the basis of the mathematical forecasting model are reexamined and the results of the mathematical forecast reported to the experts. Logical analysis plays an important role in establishing reasons for "contradictoriness" in mathematical and heuristic forecasting. When the reasons are discovered and the necessary amendments made in the forecasts that are to be combined, they are again compared and jointly processed. Obviously, the general procedure for producing a combined forecast outlined above may have specific features in each particular case.

A combination of heuristic and mathematical forecasting is the most promising means of obtaining an accurate forecast, since forecasts obtained by fundamentally different methods are subjected to joint processing.

However, in a number of cases forecasts obtained by different mathematical methods can be combined, particularly forecasts obtained with the use of mathematical models (for example, data on range tests of weapons and military equipment can be combined with data obtained under laboratory conditions by means of a computer).

The production of a combined forecast naturally makes the forecasting process more work-intensive and increases its cost (in some cases

considerably). However, in most cases forecasting problems are so complex and the demand for forecasting accuracy so high that we do not have the right to miss even the slightest opportunity of making the forecast more precise. The choice of a combined forecast depends largely on the period covered by the forecast (the lead interval) and the volume of information available to the investigator.

If the forecast is to cover a short period (for example, 1–2 years for production processes, the development of science and technology and similar processes), then, given the availability of sufficient information, the problem can be solved successfully by a mathematical method (for example, the statistical method).

In the case of longer-term forecasts (for the same processes over a period of 5–10 years), because of the possibility of sudden changes appearing in the prediction sector, the use of certain mathematical methods of forecasting may prove inadequate. In some cases they should be backed up by heuristic methods of forecasting and logical analysis of the results.

Finally, for long-term national economic forecasts (15–20 years) perhaps the only reliable method is the combined heuristic-mathematical method.

As we have said, logical analysis occupies an important place in forecasting. We shall dwell in more detail on this subject when combined forecasting is considered in chapter 8. Here we shall limit ourselves to an example which illustrates the place of logical analysis in the forecasting process.

Example 24. It can be established by a logical analysis that, for example, there is definite correspondence between the increase in the speed of military aircraft and that of transport aircraft. Actually, as is evident from figure 19, the increase in the speed of transport aircraft conforms to a law which is close to that which determines the increase in the speed of military aircraft, the only difference being a certain time lag [69]. Considering these processes as physically similar and occurring in parallel, but displaced from each other in time, we can use forecasts of the speed of military aircraft in the future for predicting the speed of transport aircraft for the same points in time.

It is pointed out that the methods of forecasting discussed above are closely related. Actually, mathematical forecasting methods make wide use of heuristics and logical analysis (primarily in the elaboration of models and analysis of results).

Heuristic forecasting, although it does not provide for the direct use of mathematical methods for forecasting, is based on the knowledge and experience of experts gained in the course of research in working with

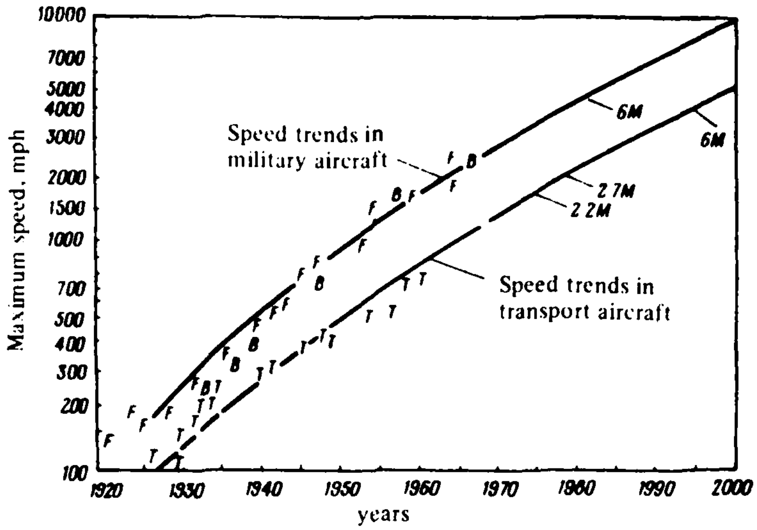


Figure 19. Speed Trends in Military and Transport Aircraft.

actual processes and their models (including forecasting models). Finally, as follows from the foregoing, heuristic elements form an integral part of logical analysis, which in a good many cases is achieved with the use of mathematics.

5. Some Examples of the Use of Forecasting

Before passing on to a more detailed consideration of the enumerated methods of forecasting, we shall give some examples of forecasting in military affairs. These examples were not selected for the significance or value of the results obtained, but simply for the purpose of illustrating the place occupied by forecasting in the process of solving military problems.

Developing a New Type of Weapon

Materials from bibliography items [37] and [34] were used for this example.

In developing a new type of weapon, beginning with the original idea and ending with its practical realization, the evaluation of its basic qualities and characteristics is inseparably linked with the resolution of such problems as:

- —determining the need to develop a new type of weapon;
- —the kinds of specifications the new weapon will have and the extent to which these specifications will exceed those of the old model;
- —the magnitude of the expenditures involved in the development, production, and operation of this weapon;

—the tactical conditions under which the weapon will be used and the changes in enemy tactics that will result from its use;
—the enemy's "technical" reaction to the production of a weapon of this type;
—the personnel requirements that servicing the new model will entail.

As is evident from a brief glance at the problems listed, each one of them is a complex scientific and technical problem, which cannot be solved without carrying out a scientifically sound research forecasting operation.

Thus, the need to develop a new type of weapon is determined on the basis of data regarding strategic and operational-tactical views combined with the data of forecasts of technical capabilities. Additionally, the resolution of this question requires a forecast of the development of the enemy's weapons and military equipment. The need to select the type of trajectory for a projected guided missile, for example, depends on forecasting the enemy's antimissile defense system. In a number of cases revolutions in technology, or a forecast that such a revolution will occur, have a determining influence on the problem under consideration. For example, the advent of nuclear weapons eliminated all doubt about the need to produce guided ICBM's. The question of whether there is a need to produce a new weapon is inseparably linked with the determination of its performance characteristics. In the first case analysis of quantitative data is the basis for the adoption of a decision regarding the need to produce such a weapon. In the second case the actual requirements which this weapon must satisfy are worked out on the basis of an analysis of a future tactical situation and existing and future capabilities. For example, in order to design the control system and warhead of a guided missile it is necessary to know a large number of the target's characteristics, such as its size, configuration, principles of motion, the arrangement of the most vulnerable elements, etc., as well as the tactics of its employment.

As a rule, modern weapons and military equipment have high cost characteristics. Therefore, great importance is attached to their military-economic analysis, based on the forecasting of expenditures involved in the development, production, and operation of the prospective model.

The final stage in the operation of producing a new type of weapon is the compilation of a manual on its tactical use, which will serve as a basis for the tactical training of troops in peacetime. This, of course, will entail the forecasting of anticipated actions on the part of the enemy.

Changes in the enemy's operations brought about by the use of the new weapon should be forecast (predicted) ahead of time, before it is

used. Otherwise the opportunity of using it most effectively will be lost, and in the event of the unexpected appearance of a new weapon on the enemy side, it would be difficult to find ways of countering it immediately. The forecasting of changes in the effectiveness of a new weapon with the passage of time is extremely important. It is entirely logical to assume that the effectiveness of a given weapon will decrease during the course of military operations. The initial high degree of effectiveness of a new weapon is explained by the unexpectedness of its use and the unpreparedness of the enemy to counter it. With the passage of time, however, the enemy will undoubtedly devise effective countermeasures against the new weapon. Therefore, in forecasting a decrease in the effectiveness of a new weapon with the passage of time, it is necessary to forecast at the same time a series of measures for its improvement and for improvements in the tactics of its employment.

Finally, in creating a new weapon, it is also necessary to answer such questions as:

- —how many people will be required to service it and what qualifications must they have?
- —which weapon will be subject to replacement by the new weapon and to what extent will the requirement for personnel be met as a result of doing away with the old weapon?
- —what will be the cost of training crews in peacetime and wartime?
- —do resources permit the necessary expenditures and are they sufficient to satisfy personnel requirements?

The answers to all these questions will make it possible to provide the information needed by the people responsible for adopting a decision on the development of a new type of weapon.

Choosing the Optimum Tactics for Combating an Enemy Weapon

Let us consider an example of a choice of optimum tactics based on forecasting conducted on the principle of logical analysis of statistical data.

Work [37] in the bibliography contains data on the losses of American ships resulting from attacks by Japanese suicide pilots. The considerable losses inflicted on U.S. naval forces by these planes compelled the Americans to consider the question of selecting the best ship maneuver for evading attacking aircraft.

As a result of an analysis of statistical data on hits on ships and aircraft destroyed, it was established that the percentage of hits on large ships (aircraft carriers, cruisers, battleships) decreased appreciably when resolute maneuvering was employed, and that the reverse was true for

small ships (destroyers, troop carriers, assault craft), i.e., the percentage increased. Logical analysis of these results showed that the reason for this lay in the nature of the effect of the maneuver on the effectiveness of a ship's antiaircraft fire. For large ships the antiaircraft fire was approximately equally effective, whether they maneuvered or not, whereas for small ships the pitching and rolling during the maneuver considerably reduced the effectiveness of their antiaircraft fire.

An analysis of data on the effect of the angle of attack of the aircraft (steep or shallow dive) showed that a steeply diving aircraft often achieved its objective in a head-on or stern attack, while an aircraft in a flat dive had the advantage in a beam attack.

The question of the influence of the relative position of the ship and the attacking aircraft was considered from two points of view: a) the firepower of the antiaircraft artillery and b) errors in guiding the aircraft onto the target.

Fire from the side is always more effective than from the bow or stern. From this point of view it can be demonstrated that it is always most advantageous for a ship to present its side to an attacking aircraft. However, in a steep dive the aircraft's range errors are approximately three times greater than lateral errors, which confirms the hypothesis that aircraft should be met beam on. In a flat dive errors in range are of no importance, while lateral errors play a determining role, therefore the bow or stern should be presented to an aircraft attacking in a flat dive. This, however, contradicts the requirement of maximum antiaircraft firepower. Analysis of statistical data showed that in this case the first factor plays the determining role.

On the basis of a logical analysis of the existing data the following recommendations were made for the optimum response tactics of ships subjected to attack:

—all ships should meet steeply diving aircraft beam on, while the bow and stern should be presented to aircraft in a flat dive;

—large ships (aircraft carriers, cruisers, and battleships) should maneuver sharply, changing course;

—small ships should maneuver slowly in order to turn towards the aircraft in the most advantageous way without reducing the effectiveness of their antiaircraft fire.

The forecast of increased safety for ships which employed such tactics was confirmed [37]. On the average, of the number of ships which employed the recommended tactics, 29 percent of those attacked were hit, compared with 47 percent of those ships which used other tactics.

Determination of Weapons Requirements

The determination of weapons requirements in future operations occupies an important place among problems involving forecasting. The level at which the problems are resolved depends upon the scale and importance of the future operation. For example, the required size and composition of a group for carrying out a reconnaissance for a battalion can be decided by the commander of the appropriate reconnaissance group. A decision about a question of the men and materiel required to carry out an offensive operation on a frontal scale involves the participation of the higher military command. However, in all cases the successful solution of the assigned problem necessitates an accurate forecast of the development of the operation and a knowledge of both our own and the enemy's capabilities with respect to weapons and equipment.

In resolving a problem of determining the number of missiles required to destroy a given target, besides the destructive power of the warhead, it is essential to take into account in the calculations a forecast of the hit accuracy for the given range, a forecast of the reliability of operation of all the units and systems of the missile, and a forecast of the presence and effectiveness of the enemy's antimissile defense.

We shall now pass on to a detailed examination of military forecasting methods.

PART II: FORECASTING IN THE SOLUTION OF MILITARY PROBLEMS

Chapter 6. Heuristic Forecasting

1. General Principles

Heuristic work occupies an important place in all phases of the forecasting process. This is determined by the nature of the dialectical method of cognition formulated by V. I. Lenin in the words "From lively contemplation to abstract thinking and from abstract thinking to practice." Actually, even in the use of mathematical methods of forecasting, heuristic elements play an important role in the analysis of available information about the process being forecast and working out its model. In strict terms heuristic forecasting is a cognitive process, directed at the study of qualitative and quantitative aspects of a future process or phenomenon, this cognition transpiring in a person's thoughts aided by mental models of the process or phenomenon. And it often happens that a person is unable to say precisely what model he used to make a particular forecast. Quite obviously, not everyone who makes daily use of heuristic forecasts in everyday life is capable of qualitatively forecasting complex processes and phenomena, in military affairs, for example. In this case the innate ability (or even talent) of the general, the military engineer, and the designer, must be supplemented by an enormous amount of knowledge and experience. Strictly speaking, experience itself is formed in the process of forecasting the results of similar phenomena, observing their operation, comparing forecasting results with practical results, and correcting the "forecasting model" accordingly. An experienced person is one who carries out such a procedure repeatedly and has at his disposal a more complete "forecasting model" than inexperienced people; and it is for this reason that experienced and competent specialists are enlisted for heuristic forecasting work.

Although wide use is now being made of mathematical methods of forecasting which rely on computers, heuristic forecasting has not lost its

importance, for in some fields (especially in military affairs) it can be difficult and, sometimes, at the present level of knowledge, simply impossible, to formulate a mathematical model (for example, of the process of armed conflict, or of control), which would permit mathematical forecasting with the required degree of accuracy. Meanwhile, man, in meeting the problems of controlling armed conflict, production, etc., has resolved and is continuing to resolve them, often quite successfully, without the use of computers and under conditions in which only partial information is available. Here we see at work that remarkable ability of the human brain of (in Wiener's words) "operating with vaguely formed concepts."

As we said earlier, heuristics originated in ancient times and was perfected during the course of man's struggle for survival. It is most suitable for solving problems where experience of past and present generations is available, and the more of this experience there is, the more effective its use. Heuristics is less effective where there is no experience—under new conditions. In such cases other methods are needed.

The development of mathematical methods of forecasting and modern computers has had an effect on heuristic forecasting. As a result of the increase in the use of computer technology for solving forecasting problems, the role of heuristic work may be reduced somewhat in the less intellectual fields, for example, in the solution of problems of an information-search nature, in carrying out preliminary factor analysis, in processing experimental data, etc. At the same time, it has made it possible to devote more attention to the creative side of the forecasting process, associated with bringing to light the principles behind the process or phenomenon being forecast.

Thus, heuristic forecasting does not exclude, but presupposes the use of, mathematical methods, while the latter not only do not undermine creativity, but provide conditions for its appearance, at the same time placing new demands on it.

Let us consider in somewhat more detail various questions relating to the use of heuristics in military affairs.

2. Heuristics in Military Affairs

A characteristic of armed conflicts, both between individuals and between groups of people, is the pursuit of opposing interests and objectives.

Owing to the fact that a condition for the achievement of his objectives is victory over his enemy, man is faced with the necessity of forecasting his enemy's actions in various situations and, on the basis of these

forecasts, to forecast and plan his own actions and calculate the forces and resources needed to achieve victory. From the moment he began to make war man came up against the feature of forecasting arising out of the fact of two opposing sides, each of which, on the one hand, is striving for maximum purposefulness and organization of his own operations and, on the other hand, the disruption of the enemy's plans and organization, "appearing wherever he [the enemy] will undoubtedly make for, while heading oneself in the direction where one is not expected" [14]. At first intuitively and later recognizing this quite clearly, man solved the following three forecasting problems:

—forecasting the enemy's actions (places, times, character, methods and directions of these actions, and the size of his forces);

—forecasting his own actions at different stages of the development of the fighting;

—forecasting the final results of the armed conflict. The solution of these closely related problems is based on a mentally formed dynamic model of the combat operations by means of which a person continuously calculates the parameters that interest him and uses this as a basis for making one decision or another. The process of man's (the commander's) forecasting and decisionmaking is the clearest example of heuristic activity.

Heuristic forecasting, like mathematical methods of forecasting, is concerned with the forecasting of both quantitative and qualitative future characteristics of a process or phenomenon. At the same time, since the quantitative and qualitative aspects of a process or phenomenon are dialectically interrelated, the heuristic processes of elaborating quantitative and qualitative forecasts are also closely related to each other. For example, a qualitative forecast of the type of battle (meeting engagement, offensive, defensive, withdrawal) is very closely related to a quantitative forecast of the troop movement rate and the forces and facilities involved, and this forecast in turn depends on a forecast of the enemy's objectives at a given stage of the fighting.

As the means of waging war evolved, so the role of forecasting (heuristic forecasting in particular) increased and the process itself became more complicated.

In the era of smoothbore weapons the outcome of combat operations (and sometimes wars as a whole) was decided by one or two battles, which were fought within the relatively small area in which the main forces of the opposing sides were concentrated [46]. For example, in the Battle of Austerlitz: "Having compelled the enemy in their attack on the retreating French troops to stretch their left flank, he [Napoleon] re-

grouped his forces in the center and struck a blow at the weakened joint. As a result, such a decisive victory was won, that within 24 hours the Emperor of Austria was forced to ask for peace" [14].*

The structure of the armies on the battlefield was characterized by its simplicity. There were only three branches of the ground forces: infantry, cavalry, and artillery. The combat operations were not of a very dynamic nature, in consequence of which the commanders had plenty of time for the organization of troop command and control [46].

A similar pattern emerged in the days of sea battles before the advent of steam power, when the slow speed of the sailing ships and the absence of air and underwater attacks made forecasting of the enemy's actions a much less difficult problem than it is today.

With the appearance of rifled and automatic weapons, the range, rate of fire, and accuracy of fire weapons increased. The motorization of armies greatly increased troop maneuverability. Combat operations were on a larger scale, more dynamic, and of longer duration. Under these conditions the volume of troop management measures increased significantly, while the conditions of implementing troop management (forecasting in particular) became considerably more complex. For the sake of comparison let us consider the scope of the Battle of Borodino, which was a general encounter in the Patriotic War of 1812, and one of the operations in the Great Patriotic War—the Jassy-Kishinev Operation [46].

In the Battle of Borodino the main forces consisted of a 135,000-man French army and a Russian army of 120,000 men, which fought each other for a period of one day in an area with a 5-km front and a depth of 4 km. The Jassy-Kishinev Operation, which lasted for 10 days, involved approximately 2,000,000 troops, more than 22,000 guns, 2,200 tanks, and over 1,500 aircraft.

Such a qualitative and quantitative increase in the means of waging war could but lead to a change in the role and content of military forecasting. Forecasting problems can no longer be solved by the heuristic method alone. Wide use is now made of mathematical methods of forecasting in conjunction with modern computer technology. Heuristic forecasting itself has also undergone substantial changes. For example, it must encompass the development of a battle within wider limits, in more dynamic forms, and take in a variety of methods of waging it. At the

* [The sense of the original is maintained, but the wording is somewhat different—U.S. Ed.]

same time, the number of parameters to be forecast (qualitative and quantitative) is continually increasing.

Whereas in former times forecasting the course and outcome of a given operation and adopting a plan to carry it out was often the responsibility of one person (the general), the carrying out of a combat operation today is impossible without the painstaking work of a staff (collective forecasting). The role of military councils is especially important.

With the advent of nuclear weapons, which marked a leap forward in developing the means of armed conflict and entailed fundamental changes in the procedures and methods of warfare, the process of forecasting was also affected by important changes.

A fundamentally new and vital problem for the commander is the forecasting of the results of using his own nuclear weapons, and also the time, the extent of the damage, and the targets against which the enemy might use nuclear weapons. Here errors in such forecasting would result in the gravest consequences.

Let us consider in general terms the role and place of forecasting in the creative activities of a commander in troop command and control. The creative process of troop command and control can be divided into the following component parts: elucidation of the mission, situation assessment, and adoption of a decision plus the implementation of the adopted decision [46]. Forecasting is involved even in the first phase of command and control—the elucidation of the combat mission. Here the commander forecasts in general terms the course and nature of the combat operations, as a result of which it becomes clear which enemy grouping will be subjected to the direct action of the troops under his control and for what period of time, what enemy counteraction he can expect and what action might be undertaken by adjacent groupings, etc.

The commander obtains more complete information for a final decision after a thorough situation analysis and forecasting work in greater depth and detail. A situation assessment is made on the basis of both existing data and a forecast of the changes to which they could be subject during the course of the battle. In turn, the forecasting is based on analysis of objective situation data. Thus, here there is a dialectical interrelationship between the situation assessment and forecasting. For example, a comprehensive assessment of the enemy will make it possible to ascertain the composition of his forces, his combat capabilities, and his strong and weak points. Given this information, it is possible to forecast the probable character of the enemy's actions. The forecasting of the

enemy's actions will be incomplete if one does not take into account the actions of his own forces, the forecasting of which is based on their assessment and the probable nature of their use as it relates to the enemy's actions.

The relationship between the decision to be taken by the commander and forecasting consists in the fact that the decision is made on the basis of a forecast of the development of the combat operations and their results. The commander examines various possible actions, then selects the most expedient course, i.e., the one that will ensure the success of the future combat operations. However, to make a sound decision before an engagement or an operation still does not mean that victory is assured. The plan must be skillfully put into effect. And this is a very complex process, involving forecasting during the course of the battle (when to attack, when and where to expect counterattacks, when and where to commit the reserves, etc.). This is more difficult than forecasting before the battle, owing to the lack of time and the characteristics of the combat situation. Moreover, it is under just such conditions that the commander must correct and refine his earlier plan, and sometimes adopt a new one, if the evolving situation requires and permits such a course of action. Thus, as follows from the foregoing, forecasting ensures purposeful troop command and control.

All the great military leaders were masters of the art of forecasting. Here, for example, is how the military theoretician Du Bocage described A. V. Suvorov: "When he appeared before the enemy, everything had been foreseen in advance. But if some event or local conditions required changing, he acted with such rapidity that no one could tell whether this change was a spontaneous creative act of the moment or the execution of the original plan" [46].

Heuristic forecasting is of great importance in the design and development of new types of weapons and military equipment, when it is essential to take into consideration, not only the resources of science, technology, and production, but other factors, such as the military-political situation, economic resources, etc., since it is not practicable to use mathematical methods in such cases on account of the difficulty of constructing suitable mathematical models.

Because heuristic forecasting is based on cognitive processes which take place in the brain, it is subjected to the influence of a great variety of objective and subjective factors that have their origin in a particular individual's character, thinking habits, and so forth. Let us consider these factors in more detail.

3. Factors Which Influence the Quality of Heuristic Forecasts

Thus, in the process of heuristic forecasting, decisionmaking is influenced by both objective and subjective factors. These objective factors include, for example, the laws of armed conflict and the conditions of a specific combat situation; subjective factors are knowledge, ways of thinking, combat experience, the commander's will, etc. At the same time, objective and subjective factors are dialectically interrelated. Subjective factors are determined by objective conditions and, in turn, actively influence them. Special importance attaches to subjective factors under conditions in which uncertainties exert an influence, i.e., in the kind of situation which occurs most frequently during combat operations.

Certain subjective factors are a prerequisite for an accurate heuristic forecast. These include, for example, an excellent knowledge of military and technical subjects, experience in scholarly and practical activities, combat experience, willpower, etc. There are, however, factors (qualities of experts) which could have a detrimental effect on the quality of forecasts. We shall dwell on some of these in more detail, since it is essential to take them into account for the successful solution of a forecasting problem by experts, as well as in the problem of the selection of the experts themselves (for technical forecasting, for example), the solution of which is one of the most important stages in the process of producing a heuristic forecast.

Under this heading we can include **professional limitation**, which is attributable both to the fact that an expert makes an assessment from the point of view of the field of knowledge in which he specializes and to the fact that there are two types of experts—highly specialized ones and those with broadly based qualifications.

A highly specialized expert, while having an excellent knowledge of his subject, does not possess the range of vision of a broadly qualified expert, who, in turn, is unable to achieve the former's level of detailed knowledge. An accurate expert forecast of large-scale problems and, as a consequence of it, the adoption of a sound, well-substantiated decision, calls for a comprehensive and, at the same time, a detailed analysis of the process being forecast and those processes and phenomena associated with it. The following is a quotation from B. H. Liddell Hart:

> The atomic bomb looked to the responsible statesmen of the West an easy and simple way of achieving a swift and complete victory and ensuring world peace. . . . But the anxious state of the peoples . . . today is a manifestation that responsible statesmen failed to think through the problem of

> attaining peace through such a victory. They did not try to go beyond their immediate strategic aim of winning the war and were content, in spite of the experience of history, to assume that military victory would lead to peace. The outcome has been the latest of many lessons that pure military strategy needs to be guided by the longer and wider view of "grand strategy" [14].*

In a good many cases it happens that an unreceptive attitude to new ideas, attributable to man's so-called **psychological inertia**, is characteristic even of highly qualified experts. This factor is determined by the different orientation of different people's thinking and as a rule does not depend on the intellectual and logical resources of their minds. An example of the following kind will suffice to convince us of this.

> None of the great representatives of the St. Petersburg School—Chebyshev, Lyapunov, Markov—recognized Riemann, whereas we are inclined to see in Riemann perhaps the greatest mathematician of the 19th century. This had nothing to do with the age factor, but with the fact that they were accustomed to a certain set of ideas, a certain kind of mathematical intuition and, as it were, an "instinctive rejection" of unusual forms of creative mathematical thinking [39].

Overcoming psychological inertia is quite a difficult problem. On the subject of the strategy of indirect actions B. H. Liddell Hart writes:

> Opposition to the truth is inevitable, especially if it takes the form of a new idea, but the degree of resistance can be diminished—by giving thought not only to the aim but to the method of approach. Avoid a frontal attack on a long established position; instead, seek to turn it by flank movement, so that a more penetrable side is exposed to the thrust of truth [14].†

* [For the interest of the reader the complete passage in the original is presented, showing by italics the omitted passages and variations in wording—U.S. Ed.

> The atomic bomb *in 1945* looked to the responsible statesmen of the West an easy and simple way of *assuring* a swift and complete victory—and *subsequent* world peace. *Their thought, Sir Winston Churchill says, was that "to bring the war to an end, to give peace to the world, to lay healing hands upon its tortured peoples by a manifestation of overwhelming power at the cost of a few explosions, seemed after all our toils and perils, a miracle of deliverance."* But the anxious state of the peoples *of the free world* today is a manifestation that *the directing minds* failed to think **through** the problem—of attaining peace through such a victory.
>
> They did not *look* beyond *the* immediate strategic aim of "winning the war" and were content to assume that military victory would *assure* peace—*an assumption contrary to the general* experience of history. The outcome has been the latest of many lessons that pure military strategy needs to be guided by the longer and wider view *from the higher plane* of "grand strategy."]

† [This and the passage in the following paragraph are so near to the original English that it has been substituted for a purely literal translation of the Russian version—U.S. Ed.]

With regard to the "method of approach," we can quote the example of objections to the mechanization of the army which

> was diminished by showing that the mobile armoured vehicle—the fast-moving tank—was fundamentally the heir of the armoured horseman, and thus the natural means of reviving the decisive role which cavalry had played in past ages [14].

Conservative thinking can often be a hindrance in heuristic work. Conservative thinking is expressed in attachment to established principles, to typical or previously recorded, strictly defined functions of a given object. This factor should really be considered as dependent on a person's intellect. Conservatism is particularly dangerous in a combat situation, since, in the words of M. N. Tukhachevskiy, "situations are too varied for permanently fixed rules to be applied to them."[1]

Combat situations are always more complex and varied than those referred to in various textbook rules and recommendations, since "any theory," in Lenin's words, "at best only projects the basic, the general, only *comes near* to embracing the complexity of life."[2] Thus, theoretical principles are not dogma, but the basis for flexible solutions.

The rejection of established views may mark the beginning of heuristic searching and creative discoveries. The history of military art provides many examples of that. Thus, the forcing of the Oder by troops of the 65th Army in accordance with army commander General P. I. Batov's plan was started, not at the end of the artillery preparation, as was usually done, but at the very beginning, on the principle "while the gunners fire, the infantry cross" [3]. The commander's forecast was fully justified, since the enemy was taken unawares by the unorthodox nature of the troops' actions and his ability to resist was undermined.

In June 1944 the Belorussian Operation was carried out, during the course of which the front inflicted two main strikes, which was somewhat of a departure from the principle which had become established by this time [43].

Difficulty in perceiving negative conclusions may have an adverse effect on the results of heuristic work in practice. This often happens when a person mistakes the desired for the actual.

Here we cite an example of two diametrically opposite forecasts of the feasibility of battleships countering aircraft. The appearance of the forecasts followed the tests by the American air force in bombing and sinking the captured German battleship *Ostfriesland* in 1921 and the obsolete American battleships *Virginia* and *New Jersey* in 1923. After these events no one doubted the feasibility of sinking undefended, slow-

moving ships, if they were subjected to a sufficient number of bombing attacks. However, there were two views of the successful encounters of aircraft with maneuvering and defended battleships in the U.S. at this time. Those who supported air power, citing the tests that had been carried out, maintained that battleships could easily be sunk by aircraft and that a surface fleet was obsolete and unnecessary. On the other hand, the advocates of battleships asserted that battleships could be reliably defended against attacks by large numbers of enemy aircraft, quoting as an argument data on hydrostabilized antiaircraft guns, which were capable of hitting targets flying at a constant speed. Franklin Roosevelt, who at that time was Assistant Secretary of the Navy and an advocate of battleships, asserted: "The day of the battleship has not passed, and it is highly unlikely that an airplane, or a fleet of them, could ever successfully sink a fleet of naval vessels under battle conditions" [73].

The history of World War II showed that there were instances of battleships being sunk by aircraft, despite the fierce resistance which they offered. However, there were also instances where, despite the damage inflicted on it, a battleship remained afloat and beat off attacking aircraft with its fire. Obviously these facts could have been foreseen. Why, then, if this is the case, were there in the U.S. at that time two diametrically opposed opinions (forecasts)? The Americans themselves answer this question thus:

> Both were blinded by self-interest. Both wanted their forecasts to be true because that would enhance the status of their own organizations. The forecaster should beware of the possibility that strong emotional ties to a specific organization, to a specific technical approach, or simply to the status quo could cause him to overlook significant facts which might alter his conclusions. In the long run such a biased forecast does no good for himself or his organization [73].

We can cite other examples.

For instance, it is well known that, prior to their attack on the Soviet Union, the leaders of Hitlerite Germany, in particular Hitler himself, were persistently reluctant to accept objective information about the fighting power of the Red Army.

Here is another well-known example. Not only did A. V. Suvorov never disregard unfavorable circumstances in forthcoming battles, he never hid them from his men. Preparing to storm Ismail, he did not hide from his 20,000 Russian troops the fact that Ismail was defended by 40,000 men led by a skillful general. "Look at that fortress," he said to the soldiers, pointing to Ismail. "Its walls are high, its moats are deep, but all the same we must capture it" [46]. A correct assessment of negative conclusions greatly facilitates the adoption of sound decisions. On the

eve of the Adda River battles in 1799 the unpopular and weak General Scherer was replaced as Commander of the French Army by Moreau, who enjoyed a distinguished combat reputation and considerable respect in the Army. Anticipating the unfavorable effect of the change on the morale of the Russian soldiers, Suvorov said, "Here I see the finger of Providence. There would be too little glory in beating a charlatan; the laurels which we shall steal from Moreau will have brighter blossoms and greener leaves." Moreau's troops, as we know, were defeated and the Russian troops entered Milan [46].

Man's tendency to exaggerate the bad was noted by Clausewitz [24]. This can cause confusion and even panic, which is inadmissible in war, for, as Suvorov said, "he who is frightened is half beaten." The success of heuristic forecasting depends largely on a person's ability to suppress this tendency. The tendency to exaggerate the bad is apparently based on the presence of an abstract (formal) possibility of something happening, when only the most general conditions for this exist. Lenin said that "every battle includes within itself the possibility of defeat."[3] But to change an abstract possibility into a real possibility of victory over the enemy it is necessary to **create** concrete conditions.

A source of hindrance in the process of forecasting is **fear of responsibility** for one's actions, which is manifested in indecisiveness and timidity. This defect was very pronounced in the commander in chief of the Russian forces, Kuropatkin, during the Russo-Japanese War [31]. "He wanted to fight, yet he was afraid to; he longed for victory, but was afraid of defeat." M. V. Frunze, referring to the necessity of instilling resoluteness and self-control in Soviet military leaders, wrote: "We need command personnel who will not lose their heads in any situation, who will be capable of making a rapid and intelligent decision, accepting the responsibility for all its consequences, and resolutely putting it into effect."[4]

Some authors refer to yet another characteristic of a person acting in the capacity of an expert—**optimism** in short-term forecasting and **pessimism** in long-term forecasting. In this case one and the same difficulties seem to a person easily surmountable in the immediate future and difficult to overcome in the remote future. As a result of this trait in some experts their short-term forecasts are overstated and their long term ones understated.

We have mentioned a number of factors which have a negative effect and limit the potential of heuristic forecasting. We shall now consider the factors without which it would be difficult (and in some cases simply impossible) to produce an accurate forecast.

First and foremost under this heading we must place **thorough knowledge** of the subject of the forecast and Marxist-Leninist theory, **taking into consideration and utilizing the experience** of former generations, for, as F. Engels wrote: "Science advances in proportion to the volume of knowledge inherited by it from the preceding generation. . . ."[5]

Only by knowing the nature of combat, its laws and regularities, and the capabilities and characteristics of weapons and military equipment is it possible to forecast every conceivable turn and change in the course of an engagement or encounter. Moreover, it is essential not only to know, but to be able to apply knowledge acquired in practice. Here it is appropriate to quote the words of Suvorov, who in answer to an assertion by the Austrians to the effect that he was lucky, said: "Luck once, luck a second time! For God's sake! Once in a while it is ability as well!" [46].

Under present-day conditions the role of this factor has increased immeasurably. Now as never before, the words of Engels have a topical ring: ". . . When the waves of the technical revolution are lapping around us . . . fresher, bolder minds are needed. . . ."[6]

Intuition is an extremely valuable characteristic of mental activity.

Speaking on this subject, M. V. Frunze said: "In order to be a good strategist, in the field of pure politics and in military affairs alike, special qualities are needed. The most important of these is so-called intuition, the ability to analyze rapidly the surrounding phenomena in all their complexity, to select the most fundamental, and on the basis of a consideration of this phenomenon to plan the struggle and the work."[7] According to Clausewitz's definition: "The greater and lesser part of this intuition undoubtedly consists in the semiconscious comparison of all the quantities and circumstances, by means of which all that is unimportant and unessential is eliminated, while the more essential and predominant factors are recognized more rapidly than by strictly logical inference" [24].

Thus, intuition is a special cognitive process, which is distinguished from normal logical thinking, not only by its rapidity of action, but by its "semiconscious" character. Intuition is undoubtedly a remarkable capacity in man. However, it would be wrong to explain it simply as a talent of the one who possesses it. For example, Clausewitz wrote that intuition "is not only a natural talent, but mainly the result of practice, which familiarizes one with phenomena and almost turns into a habit the discovery of truth, i.e., soundness of judgment" [24]. Thus, intuition is based on all past experience, the entire sum of knowledge, and is formed in the process of considerable labor. The following statement, made by

Napoleon, is very interesting in this connection: "If it seems that I am always ready for everything, the explanation for this is that before undertaking anything I have already reflected upon it for a long time; I have foreseen what might happen. No genius suddenly and mysteriously reveals to me precisely what I must say and do in circumstances which to others seem unexpected. Rather, this is revealed to me by my reflections. I am always working, while dining, while at the theatre; I wake up at night in order to work" [46].

Of great importance in creative work is the **ability to pick out what really matters** and discard the nonessential. As follows from the foregoing, in some cases such a problem can be resolved intuitively, in others the solution entails a long and painstaking process of investigation. It should be noted that this process always takes place in the construction of models of processes and phenomena to be studied. In his *Creative Autobiography** Einstein said of this process: "A vast number of insufficiently coordinated facts were at work . . . which were overwhelming. But I soon learned to seek out that which could lead into the heart of the matter and reject all the rest, all that overloads the mind and distracts one from the essential."

Another important factor which facilitates fruitful heuristic work was noted by K. A. Timiryazev: "A disciplined imagination has always lain behind every scientific discovery. All the great scientists were, in a certain sense, great artists. A person who has no imagination can collect facts, but he will not make a great discovery."[8]

As an example we quote the statement of U.S. Congressman O. Ferriss concerning the purchase of Alaska from Russia: "Of what possible commercial importance can this territory be to us? It cannot serve as a stopping place for vessels passing across the Pacific Ocean from one continent to the other. . . . The perpetual fogs in which these regions are enveloped render regular navigation by ocean steamers highly dangerous and utterly impracticable. . . . This territory is no more useful and important for navigation of the Pacific than Greenland is for navigation of the Atlantic" [73]. It is hard to dispute arguments such as these by Ferriss. He did not, however, have the imagination to take into consideration a great variety of other factors which would have changed his forecast radically. Actually, "he should have been able to see that an area as large as Alaska was virtually certain to contain something valuable. In fact, the total value of gold extracted from Alaskan mines between 1880 and 1957 was $722 million, or 100 times the purchase price of $7,200,000. Additional income from silver, copper, and fishing in-

* [No such title in English is assigned to works of Einstein investigated—U.S. Ed.]

creased still further the profit resulting from this purchase" [73].*

A commander's flexibility of thought and his ability to foresee the development of an armed conflict and rapidly make correct, sound decisions are not only the consequence of profound knowledge, aptitude, and talent, but of extensive **moral and psychological training.** Here special importance attaches to such character traits as willpower and determination, since without them a commander will display uncertainty, even in cases where a solution has been found which meets the conditions of the situation.

Describing the qualities of a commander in chief, Napoleon said: "The first quality of a commander in chief is the possession of a cool head, which reflects objects faithfully, is never influenced by passions, and does not let itself be blinded or upset by good or bad news" [53]. At the same time, he considered that will and intellect should be in equilibrium: "A military man must have as much character as intellect" [38], for if his will is greater than his intelligence, a general will act resolutely but irrationally, conversely, he will have good ideas and plans but insufficient resoluteness to put them into effect. On the subject of character we should consider yet another very important trait, namely **the ability to acknowledge one's mistakes in time,** which is particularly important for people possessing great authority and whose opinions, because of this, naturally influence the opinions of others. Very noteworthy in this sense is Marshal of the Soviet Union S. S. Biryuzov's opinion of Fedor Ivanovich Tolbukhin: "From Fedor Ivanovich's very first words it became clear to us that, having visited the 5th Shock Army and the 57th Army, he had come to the conclusion that these armies did not occupy the most advantageous positions for delivering the main thrust, and yet, you know, before the reconnaissance parties had been sent out, Tolbukhin had thought otherwise! And now he frankly acknowledges his mistake. . . . This man, who had been able to master himself so resolutely in the interest of the cause, grew still taller in my eyes" [4].

Having considered the qualities which experts ought (or ought not) to possess, it should be noted that every expert (scholar, leader, commander), being human, possesses both positive and, in some degree or other, negative qualities. If he recognizes the possibility of being influenced by the above-mentioned negative traits, this will help him to avoid (or at least minimize) the effect of these shortcomings on the results of forecasting.

4. The Practice of Heuristic Forecasting

Throughout the course of history an enormous amount of practical experience has been accumulated in the use of heuristic forecasting in

* [These passages follow the English original rather closely—U.S. Ed.]

military affairs. This experience serves as a basis for training people in troop command and control and the direction of combat operations. It should be noted, however, that historical sources contain mainly the results (positive and negative) of the use of forecasts in decisionmaking and few contain descriptions of examples of the elaboration of the forecast itself. Nevertheless, despite the fact that no two encounters or engagements are identical, knowledge of this experience is essential for sound forecasting and decisionmaking in each new concrete situation.

Emphasizing the importance of studying the history of wars, Napoleon said: "Read and reread the campaigns of Alexander, Hannibal, Caesar, Gustav Adolf, Turenne, and Frederick and model yourself on them. This is the natural way to become a general and learn the secrets of the military art. Higher tactics can only be learned from experience and the study of the campaigns and battles of great generals" [38].

There are innumerable examples of the accurate forecasting of the enemy's actions and the appropriate actions of our own troops by famous generals and military leaders.

Suvorov's operations at the Battle of Rimnicu, when the Russo-Austrian forces, numbering 25,000 men, annihilated a Turkish army of 100,000, provide a superb example of the results of a surprise attack, strictly calculated and based on forecasting [46].

Kutuzov's brilliant foresight of the consequences of a surprise turn of the Russian troops onto the Staraya Kaluzhskaya Road in 1812, following Napoleon's abandonment of Moscow, resulted in the subsequent defeat and annihilation of the French forces [46].

A capacity for accurate forecasting was amply demonstrated by the great Soviet military leaders during the Great Patriotic War. Here is what P. N. Lashchenko says about I. D. Chernyakhovskiy in his memoirs:

> I always admired the 37-year-old commander's ability to foretell, not only the nature and special features of an impending battle, but all the possible changes during the course of its dynamics, right down to details which might somehow or other affect the success of troop operations. Constantly and sensitively feeling the pulse of the battle, knowing in detail the mission of each regiment or even battalion operating in independent sectors, Chernyakhovskiy never frittered away his energy on trifles, never immersed himself in them. All his decisions were distinguished by breadth and boldness of concept and that element of risk which, being based on a subtle analysis of the situation and precise calculations, made it possible to implement these decisions with maximum effect [30].

The Soviet Command worked out operations plans based on forecasts of the countermeasures which the enemy might take. Thus, for

example, the plan of the offensive of the Soviet forces at Stalingrad took into account the possibility of an enemy attempt to break the ring of encirclement from outside, and for this reason it provided for the implementation of measures including, for example, the creation of sufficiently powerful reserves for the repulse of such attacks, particularly in the region of Kotel'nikovo, and the mounting of fresh attacks (in the region of Novaya Kalitva and Monastyrshchina) to expand the ring of encirclement and provide it with strong operational support [46]. The measures adopted contributed to the achievement of the great victory on the Volga.

When a heuristic quantitative forecast is based on the questioning of a number of experts (which happens, for example, in forecasting the characteristics of weapons and military equipment), a number of problems arise in connection with the organization of the selection and questioning of the experts and the processing of the resultant answers.

The correct selection of the experts is linked with the problems of determining their qualifications (competence in the subject under consideration), and of taking into account the above-mentioned factors and traits of experts that influence the quality of forecasting. At present there are practically no objective methods of assessing the competence of experts or the presence or absence of particular traits in the experts; therefore, the method of self-assessment is employed, in which the specialists assess their own and other experts' competence. During questioning an expert is invited to name several individuals whom he considers competent in the matter under discussion. A widely used method of organizing the interrogation of experts is the above-mentioned Delphi method and its modifications [67]. In this case the questioning is based on the following principles:

—the questioning is conducted in several rounds;
—the answers are given in numerical form;
—after each round the results are processed statistically and all the experts questioned are acquainted with the answers of the other participants;
—the experts are required to substantiate their opinions and the reasons given are communicated to the other participants;
—the experts give their answers independently of each other.

Direct communication between specialists is eliminated in the Delphi method and is replaced by a program of consecutive individual questionings. This makes it possible to avoid a number of psychological factors which intrude excessively during the course of group discussions.

The success of expert questioning depends largely on the precision with which the questionnaires are formulated to eliminate ambiguity. This in turn imposes certain demands on the form of the questionnaire, which should require of the expert the minimum time for the formulation of the results.

The processing of the results of an expert questionnaire survey depends on the type of information obtained from the experts.

If each of N experts participating in a questionnaire survey gives (as requested in the questionnaire) one value of y_j (j is the number of a given expert) of a future value of the quantity being forecast, then as a result of processing N values of y_j, the following indices can be obtained:

—the average value of the expert estimates (point forecast of a given group of experts), which characterizes the general opinion of the experts:

$$\hat{y}_{ex}=\frac{1}{N}\sum_{j=1}^{N} y_j; \tag{1}$$

—the variance of the estimates, which characterizes the variation of opinion (point forecast) of individual experts relative to a mean value of $\hat{y}_{ex}$:

$$\hat{D}(y)=\frac{1}{N-1}\sum_{j=1}^{N}(\hat{y}_{ex}-y_j)^2; \tag{2}$$

—the root-mean-square deviation, which characterizes the indicated variation, in a dimension corresponding to that of variable y:

$$\hat{\sigma}=\sqrt{\hat{D}(y)}; \tag{3}$$

—the coefficient of variation, which may characterize the degree of accord of the experts:

$$v=\frac{\hat{\sigma}}{\hat{y}_{ex}}. \tag{4}$$

The smaller the coefficient v, the more unanimous the experts are assumed to be.

The resultant indices can also be used to forecast the dimensions of the region into which with a given probability P the future value of the quantity being forecast will fall, since, as we have already said, there is no reason to expect that the future value of variable y being forecast will correspond exactly with $\hat{y}_{ex}$.

The region of the future value of the quantity being forecast will be defined as follows:

$$\hat{y}_{ex} - \Delta_1 \leqslant y \leqslant \hat{y}_{ex} + \Delta_2. \qquad (5)$$

To plot the indicated domain (to define Δ_1 and Δ_2) it is necessary to make an assumption about the form of the distribution law of the sum of variables y_j. Very often the distribution law is assumed to be normal, an assumption which is more justified the greater the number of participating experts. In particular, where $N \geqslant 10$, it can be assumed that this law is approximately normal [11].

For a symmetrical law $\Delta_1 = \Delta_2 = t\frac{\hat{\sigma}}{\sqrt{N}}$, where t is the quantity being determined with a given probability P for a given concrete law.

For a normal distribution law of experts' estimates, it is established that quantity t has a Student distribution with $N-1$ degrees of freedom. This is determined from the tables in bibliography item [5] depending on $N-1$ and $1-P$. In particular, for $P = 0.95$ and $N-1 = 10$, $t = 2.23$

$$\hat{y}_{ex} - 2{,}23\frac{\hat{\sigma}}{\sqrt{N}} < y < \hat{y}_{ex} + 2{,}23\frac{\hat{\sigma}}{\sqrt{N}}.$$

From the point of view of mathematical statistics initial data (y_i) which deviate significantly from the mean ($\hat{y}_{ex}$) are assumed to be entirely accidental (random "overshoots") and in some cases are even excluded from the analysis altogether.

Here we shall introduce the concept of "contradictoriness" of the opinion of the kth expert in relation to the generalized opinion of all the experts.

Let us assume that the opinion of the kth expert y_k is extreme compared with the opinions of N experts. Because (as a rule) the actual value of variance $D(y)$ is unknown to us, and only its estimated value $\hat{D}(y)$, determined by means of expression (2), is known, we make a mathematical assessment of the contradictoriness of the kth expert's opinion by using N. V. Smirnov's method for estimating the abnormality of results where the general variance is unknown. The essence of this method consists in the following.

A calculation is made of the probability that quantity $t = \frac{y_K - \hat{y}_{ex}}{\sqrt{\hat{D}(y)}}$*

will exceed a certain predetermined maximum β:

$$\alpha = \text{Prob}\, \{y_k - \hat{y}_{ex} > \beta \sqrt{\hat{D}(y)}\}. \qquad (6)$$

If this probability is sufficiently great (for example, greater than 0.05–0.10), then the hypothesis that y_k is abnormal can be rejected, otherwise, it is accepted. In this connection we shall consider as "contradictory" the opinion y_k for which the inequality

$$y_k - \hat{y}_{ex} > \beta \sqrt{\hat{D}(y)} \qquad (7)$$

is fulfilled with a probability less than a certain limit α′. Usually a quantity of the order of 0.05 or less is taken as α′.

Values of coefficient β, which satisfy condition (6), are given in table 7.

Table 7.

N	α		
	0.10	0.05	0.01
	Values of β		
3	1.15	1.15	1.15
4	1.42	1.46	1.49
5	1.60	1.67	1.75
6	1.73	1.82	1.94
7	1.83	1.94	2.10
8	1.91	2.03	2.22
9	1.98	2.11	2.32
10	2.04	2.18	2.41
11	2.09	2.23	2.48
12	2.13	2.28	2.55
13	2.18	2.33	2.61
14	2.21	2.37	2.66
15	2.25	2.41	2.70
16	2.28	2.44	2.75
17	2.31	2.48	2.78
18	2.34	2.50	2.82
19	2.36	2.53	2.85
20	2.38	2.56	2.88
21	2.41	2.58	2.91
22	2.43	2.60	2.94
23	2.45	2.62	2.96
24	2.47	2.64	2.99
25	2.49	2.66	3.01

*[The reader will note this recurrence of the problem of the use of a Cyrillic K in a context where otherwise Latin italic *k*'s appear—U.S. Ed.]

The fulfillment of inequality (7) provided $\alpha<\alpha'$, is thus a mathematical indication of the presence of a contradictory opinion (or opinions) among a given group of experts.

It should be noted that this indication can be used only for a normal distribution of experts' opinions. As experience shows, in many cases this distribution can be considered normal.

The table was compiled for a case where the probability α of a deviation of the maximum value of the point forecast from the mean (the generalized opinion of the experts) is being considered. By virtue of the symmetry of normal distribution, this table can also be used for a case where probability α of the deviation of the minimum value of the point forecast from the mean is being considered.

In estimating the probability α^* of the maximum deviation (in terms of the modulus) of the point forecast from the mean, it is necessary to take into consideration the following relation

$$\alpha^* = 2\alpha. \tag{8}$$

For values of $N>25$, α can be found from the approximate expression

$$\alpha = \frac{N}{2}\left[1 - \Phi\left(t\sqrt{\frac{N}{N-1}}\right)\right], \tag{9}$$

where Φ is a Laplace function.

Example 25. Let us consider an example of the assessment of the contradictoriness of an expert's opinion. We shall assume that, as a result of questioning experts ($N = 10$), we obtained the following values of point forecasts of the future value of a technical specification: $y_1 = 10$; $y_2 = 8$; $y_3 = 15$; $y_4 = 11$; $y_5 = 13$; $y_6 = 12$; $y_7 = 9$; $y_8 = 10$; $y_9 = 8$; $y_{10} = 11$.

We determine in accordance with equation (1) the point forecast of this group of experts

$$\hat{y}_{ex} = \frac{10 + 8 + 15 + 11 + 13 + 12 + 9 + 10 + 8 + 11}{10} = 10.7.$$

We assess the "contradictoriness" of the third expert's opinion—$y_3 = 15$. In accordance with equation (2) we find the variance estimate

$$\hat{D}(y) = \frac{1}{9}(0.7^2 + 2.7^2 + 4.3^2 + 0.3^2 + 2.3^2 + 1.3^2 + \\ + 1.7^2 + 0.7^2 + 2.7^2 + 0.3^2) = 4.9.$$

According to table 7 for $N = 10$ and $\beta = \frac{15 - 10.7}{\sqrt{4.9}} = 1.94$ we find that $\alpha > 0.10$. Consequently, inequality (7) if fulfilled with a probability $\alpha > \alpha' = 0.05$, and there is no reason to consider the third expert's opinion contradictory.

If an extreme point forecast proves contradictory, the forecast closest to it is verified, and so on, until a noncontradictory forecast is indicated.

It should be noted, however, that fulfillment (or nonfulfillment) of the condition of contradictoriness may depend on the magnitude of probability α'. One and the same opinion of a particular expert may be contradictory for one probability α' and noncontradictory for another. Therefore, the specified criterion in this sense is conditional and should be supplemented by logical analysis, taking into account the requirements for accuracy of the forecast and physical and other limitations (which, generally speaking, the experts also should take into account).

In processing the results obtained from the questioning of experts it is also essential to keep in mind the following. The contradictoriness of an expert's opinion may be explained by the fact that he can foresee better than the others the development of a given process in the future and, therefore, "drops out" of the region which characterizes the opinion of his colleagues. For this reason it is essential to pay very close attention to the extreme points of expert questionnaire surveys, after a careful study of the experts' arguments *in* support of their estimates, and acquaint the other experts with this opinion.

Thus, the sequence of operations in evaluating the results of questioning experts who submitted forecasts y_j ($j = 1, 2, \ldots, N$) of the future value of variable y may be as follows:

—the generalized opinion of the experts (point forecast) is determined by means of expression (1);
—the variance and toot-mean-square deviation of the experts' opinions are determined by means of expressions (2) and (3);
—the contradictoriness of experts' extreme opinions is evaluated by means of logical analysis and inequality (7);
—if the experts' opinions are noncontradictory, the results of the questioning are drawn up in the form of point (1) and interval (5) forecasts;
—If the opinions are contradictory, a second round of questioning is carried out (with discussion of the results and opinions of the first round) in order to obtain agreement with the members of the group in question (or, if necessary, by enlisting other experts).

A more convenient form of evaluation and the one most willingly accepted by experts is that of obtaining the feasible limits of the quantity

to be forecast. If each of N experts participating in a question and answer survey gives two (a minimum y_j^{min} and a maximum y_j^{max}) values between which in his opinion the future value of the quantity in question will be found, the results of the survey can be processed as follows.

First of all, it is necessary to decide on the form of the distribution law of the quantity being forecast between the extreme estimates of each expert. In particular, we can select as such an a priori distribution law the equal density law:

$$f(y_j)=\frac{1}{y_j^{max}-y_j^{min}}, \quad y_j^{max}<y_j<y_j^{min},$$

$f(y_j) = 0$ in all the remaining cases.

Here the average values (point forecast) given by the jth expert is determined by the formula

$$\hat{y}_j=\frac{1}{2}\left(y_j^{max}+y_j^{min}\right). \tag{10}$$

The point forecast of the whole group of experts (where there is equal confidence in each of them) according to formula (1) will be

$$\hat{y}_{cx}=\frac{1}{N}\sum_{j=1}^{N}\hat{y}_j. \tag{11}$$

The variation of the point forecasts of individual experts with respect to $\hat{y}_{cx}$ is found from the expression

$$\hat{D}(y)=\frac{1}{N-1}\sum_{j=1}^{N}(\hat{y}_{cx}-\hat{y}_j)^2, \tag{12}$$

while the coefficient of variation which characterizes the degree of unanimity of the experts with respect to the forecasts is found by means of formula (4).

In addition to the above forms of estimates given by experts during forecasting, there may also be a case (although encountered very rarely) in which the experts give three estimates:

—the maximum value of the quantity being forecast y_j^{max};
—the minimum value of this quantity y_j^{min};
—and its most probable value y_j^{mod}.

In this case we can use, for example, a variety of β-distribution as the distribution of the estimates of each expert.

The problem here, as before, consists in determining the average value and the variance which characterize the opinion of each expert and finding the generalized opinion of all the experts by using relations (1), (2), and (5).

The region of the future value of the quantity being forecast, as in the previous case, is determined from expression (5). A mathematical evaluation of the degree to which any expert's point forecast contradicts the generalized opinion can also be given by the described method using expressions (6)–(9).

In principle, certain mathematical indicators which characterize the competence and temperament of the experts can be calculated from the answers they give to questions.

Such criteria may be:

—coefficient of variation

$$v_j = \frac{\sqrt{D_j(y)}}{\hat{y}_j}, \tag{13}$$

where

$$D_j(y) = \frac{1}{12}\left(y_j^{\max} - y_j^{\min}\right)^2, \tag{14}$$

which characterizes the decisiveness (conviction) of an expert about his evaluation (an expert with a smaller value of v_j is more categorical in his evaluation) and also indirectly characterizes the expert's competence (the more thorough his grasp of a given question, the more closely the limits $y_j^{\max}$ and $y_j^{\min}$ will agree with the physically possible limits of the future value of the quantity being forecast);

—the quantity

$$\xi_j = \frac{\hat{y}_j - \hat{y}_{ex}}{\hat{y}_{ex}}, \tag{15}$$

which characterizes both the competence of the jth expert from the point of view of the current level of knowledge about the object being forecast and is manifested in quantity $\hat{y}_{ex}$ (an expert with a smaller value of ξ can be considered more competent), and certain character traits; a cautious expert will have a negative ξ_j value (if development proceeds by way of an increase in y), since $\hat{y}_j—\hat{y}_{ex} < 0$, whereas a bold expert gives an evaluation which exceeds $\hat{y}_{ex}$ and his $\xi_j > 0$. Reasoning from this, we can say that experts with values of the specified indicators that are smaller with respect to the modulus are more preferable. In addition to indicators which characterize the qualities of individual experts, others can be obtained which characterize the entire group of experts as a whole.

One such indicator, the coefficient of variation, which characterizes the unanimity of the experts on the generalized point forecast and can be determined by expression (4), has already been mentioned. An increase in this coefficient indicates a discrepancy in the experts' opinions. However, this discrepancy may vary in nature. It can be "uniform," i.e., the experts' opinions can be evenly spread over the entire region between the extreme point forecasts. In this case the discrepancy in the experts' opinions can be both the objective consequence of the nature of the process being forecast (the influence of a large number of uncertainties attending the process being forecast and not investigated up to the present moment of time) and the consequence of a lack of competence on the part of a number of the participating experts.

The coefficient of variation also increases if there are several (two as a rule) groups of opinions, although within each group there is unanimity of opinion among them. Whereas in the first case it is possible (given confidence in the competence of the experts) to utilize their generalized opinion, it is necessary in the second case to take steps to reconcile the experts' opinions (by carrying out another questioning and discussion of the results of the first questioning, bringing in other experts, etc.). A discrepancy of the second type may occur, in particular, if, during the process of questioning conditions were such that steps were not taken to ensure independent evaluations (evaluations were influenced by intercommunication among the specialists, the opinions of authorities, etc.). Unfortunately, the magnitude of the coefficient of variation (4) does not provide the answer to the question of precisely what type of discrepancy exists among the opinions.

However, the type of discrepancy can be ascertained by a graphic representation of the experts' opinions. In forecasting the outcome of future events with two possible conditions (the yes–no type), the second type of discrepancy occurs when the numbers of "yes" and "no" votes are approximately equal.

A coefficient of variation for the entire group of experts, similar to coefficient v_j for the jth expert, is the relationship

$$v' = \frac{1}{\hat{y}'_{\text{ex}}} \left[\frac{1}{N} \sum_{j=1}^{N} D_j(y) \right]^{\frac{1}{2}}, \tag{16}$$

which is a generalized characteristic of the decisiveness and competence of the group of experts as a whole.

The similarity of the group in temperament can be characterized by the coefficient

$$v'' = \frac{\sqrt{D[D_j(y)]}}{\frac{1}{N} \sum_{j=1}^{N} D_j(y)}, \tag{17}$$

where

$$D[D_j(y)] = \frac{1}{N-1} \sum_{j=1}^{N} \left[D_j(y) - \frac{1}{N} \sum_{i=1}^{N} D_i(y) \right]^2 .$$

The indicators cited above permit a comparison of the experts or groups of experts to be made. However, to establish the quantitative limits of the mathematical indicators which characterize the conformity of a given expert (group of experts) to a specific type of evaluation (a group is homogeneous–nonhomogeneous, an expert is competent–incompetent) necessitates additional research.

Where the degree of confidence in an expert is determined by the magnitude of the variation of his evaluation [see expression (14)], the point forecast of the entire group of experts can be determined from the expression

$$\hat{y}'_{\text{ex}} = \sum_{j=1}^{N} w_j \hat{y}_j, \tag{11'}$$

where

$$w_j = \frac{1/D_j(y)}{\sum_{i=1}^{N} 1/D_i(y)}$$

is the "weight of opinion" of the jth expert, as distinct from the weight of $1/N$ in expression (11).

Here $\sum_{j=1}^{N} w_j = 1$, in the same way as $\sum_{j=1}^{N} \frac{1}{N} = \frac{N}{N} = 1$.

We shall give without proof an expression for the dispersion of the point forecasts of individual experts with respect to $\hat{y}_{ex}$, determined from expression (11'), reasoning from the assumption that the expected value of the point forecast of the jth expert is equal to the actual value of the quantity being forecast, which (dispersion) in this case will be characterized by the variance

$$\hat{D}(y) = \frac{\sum_{j=1}^{N} w_j (\hat{y}_{ex} - \hat{y}_j)^2}{\sum_{j=1}^{N} w_j (1 - w_j)}. \qquad (12')$$

It is not difficult to see that provided $w_j = \frac{1}{N}$, expressions (11) and (12) represent a particular case of the more general expressions (11') and (12').

Example 26. As an example we shall consider the heuristic forecasting of a certain technical specification A in the year 19__. The results of questioning a group of nine experts are given in table 8.

Table 8.

Experts	Value of characteristic	
	A_j^{min}	A_j^{max}
1st	3.0	3.9
2nd	3.9	4.5
3rd	3.4	4.5
4th	3	3.4
5th	3	3.4
6th	2.7	3
7th	2.8	3.1
8th	2.4	3.0
9th	2.2	2.6

The results of calculations obtained by using the relationships given above are contained in table 9.

These tables illustrate the effect of the method of processing the experts' forecasts on the final result of heuristic forecasting.

The discrepancy in the forecast is due to the fact that in the second case the opinion of the jth expert was considered with a weight inversely proportional to its variance. This made it possible to reduce the variance of the heuristic forecast (by reducing $\hat{D}(A)$ from 0.34 to 0.31). However, as we have already mentioned, the method of "weighing" the experts' opinions cannot always be used in all cases, therefore, the most commonly used principle is that of equal confidence, in which all the experts' opinions are assumed to be of equal weight $(\frac{1}{N})$.

In the example under consideration the indicated discrepancy in the forecasts is insignificant. This is explained by the fact that the experts involved in the questioning were equally well informed (about the question being studied), unanimous, and differed little in temperament.

In fact, none of the opinions was contradictory. In particular, the most extreme opinion (that of the second expert), $\hat{A}_2 = 4.2$, according to expression (6) and table 7, has $\alpha > 0.10$.

The experts' opinions (point forecasts) were evenly distributed in the interval between $\hat{A}_9 = 2.4$ to $\hat{A}_2 = 4.2$, which indicates the absence of two groups of opinions.

The values of the indicators characterizing the competence and temperaments, both of individual experts and the group as a whole, are given in table 10.

As an analysis of the data in the table will show, the variability v_j of the experts was quite small. The "boldness" of the eighth and ninth experts ($\xi_8 = -0.18$, $\xi_9 = -0.27$) is offset by the "caution" of the second and third experts ($\xi_2 = +0.28$, $\xi_3 = +0.23$), because of the fact that the group as a whole was unanimous ($v = 0.18$ is a small quantity), sufficiently decisive and competent ($v' = 0.05$, $v = 0.18$ are small quantities). The quantity $v'' = 0.96$, *which is close to unity, characterizes the homogeneity* of the group. However, as we have already said, the degree of homogeneity can be determined only on the basis of processing the indices of different groups when establishing the respective quantitative boundaries.

Thus, in the opinion of a given group of experts (where their opinions are all of equal "weight") the value of technical specification A in 19__ will be found in the range 3.3 ± 0.58.

5. Errors and the Field of Application of Heuristic Forecasting

As is evident from the foregoing, the heuristic method of forecasting is the oldest method used in military affairs.

The main defect of this method is that it involves a certain subjectivism in the evaluation of a future situation, the influence of which on the result of forecasting can be minimized if the group questioning of the experts is conducted so that the questioning procedure itself and the processing of the results are properly organized. The basic requirements for the selection of experts for questioning and the processing of the resultant answers have been considered above.

Table 9.

Quantity	Experts									Form of relationship
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	
$\hat{A}_j$	3.5	4.2	4.0	3.2	3.2	2.9	3.0	2.7	2.4	(10)
$D_j(A)$	0.044	0.023	0.099	0.023	0.023	0.011	0.011	0.023	0.011	(14)
	Equal weight of experts' opinions $\left(\frac{1}{N} = \frac{1}{9}\right)$									
$\hat{A}_{ex}$	3.3									(11)
$\hat{D}(A)$	0.34									(12)
Interval forecast $P = 0.95$	3.3 ± 0.58									(5)
	Different weight of experts' opinions									
w_j	0.047	0.093	0.023	0.093	0.093	0.186	0.186	0.093	0.186	
$\hat{A}_{ex}$	3.1									(11')
$\hat{D}(A)$	0.31									(12')
Interval forecast $P = 0.95$	3.1 ± 0.56									(5)

Table 10.

Quantity		Experts									Form of relationship
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	
υ_j		0.06	0.04	0.08	0.05	0.05	0.04	0.04	0.06	0.04	(13)
ξ_j	equal weight	+0.05	+0.28	+0.23	0	0	−0.09	−0.09	−0.18	−0.27	(15)
	diff't weight	+0.09	+0.33	+0.28	+0.05	+0.05	−0.05	−0.05	−0.14	−0.23	
υ	equal weight					0.18					(4)
	diff't weight					0.18					
υ'	equal weight					0.05					(16)
	diff't weight					0.05					
υ''						0.96					(17)

An important virtue of the heuristic method is that it provides for the forecasting of abrupt changes in the development of the process in question, because, as a rule, it involves the participation of highly qualified and experienced experts. This virtue, which makes it possible to avoid gross errors in forecasting in cases where such abrupt changes are indicated, foreshadowed the wide use of the heuristic method both in the past and at present. There is no reason to suppose that the requirement for heuristic forecasting will diminish in the future.

We shall dwell in somewhat more detail on the errors of the heuristic method of forecasting.

The actual errors of a heuristic forecast (as indeed of a forecast produced by any other method) can be accurately determined only when the event being forecast occurs. In this case the error of a qualitative forecast is determined by whether or not the process being forecast acquired the anticipated quality. For example, if a future armed conflict was forecast as a "meeting engagement" and the enemy in fact withdrew, the forecast would not have been justified. In other words, an evaluation of the accuracy of a qualitative forecast is made on a "yes–no" basis.

The error of a quantitative forecast is determined by the difference between the actual value of the quantity being forecast and its forecast value.

However, as we have already mentioned, an evaluation of the accuracy of a forecast at the moment of fulfillment of the event being forecast is of little value from the standpoint of the possibility of influencing the event, since such an evaluation amounts to a simple statement of the fact of the presence and magnitude of the forecasting error.

An a priori evaluation of the accuracy of a forecast (at the time of producing it) is of much more value, since in this case the person making the decision (and it is precisely for this reason that a forecast is made) obtains additional information, from which he can judge the usefulness of the forecast for the process of working out a decision.

In the case of mathematical forecasts (owing to their specific character) which involve the use of mathematical models, there are strict relationships, which enable us to estimate the statistical characteristics of the future forecast error.

An a priori estimate of the accuracy of heuristic forecasts compared with mathematical forecasts is difficult for a number of reasons. If one person makes a forecast (for example, a commander assessing a situation), it is impossible for the future error of his forecast to be objectively

evaluated a priori, since we do not know the "model" which he "used for the calculations." In this case one must rely on his authority, which, however, is in some measure an objective index of the quality and accuracy of his performance (including the forecasting of other situations) in the past.

If heuristic forecasting is based on the results of questioning experts, an a priori judgment of its accuracy can be made, using the statistical characteristics of the discrepancy in the opinions of the individual experts in relation to the mean value of the forecast (the generalized opinion of the experts) on the assumption that this mean is not biased, i.e., its expected value agrees with the future value of the process being forecast. In this case a small discrepancy in the opinions with respect to the generalized opinion (the unanimity of the experts) increases the confidence of the person or persons making a decision in the accuracy of the given forecast.

From the point of view of mathematical statistics an evaluation of the forecasting accuracy of a particular expert (or group of experts) could be made, if one had information about the errors made by this expert (or group of experts) in the past. However, in this case we are faced with difficulties associated, firstly and as a rule, with the small amount or lack of information about forecast errors in the past (particularly if it is a matter, for example, of forecasts for a period of ten years or more, when such data may be completely lacking); secondly, with the variety of the processes being forecast and the conditions under which the forecasting process is carried out; thirdly, with the fact that increasing knowledge with the passage of time and the experts' experience may attribute existing information about forecast errors (supposing there are any) from the point of view of mathematical statistics to "different general aggregates."

It should be noted, however, that although such information complicates the a priori evaluation of an error in a given concrete forecast made by a given expert or experts, it is very valuable input information for the solution of the problem of selecting experts, the success of which largely determines the success of heuristic forecasting.

On the matter of the field of application of heuristic forecasts, it should be noted that they are most widely used in the investigation of processes whose mathematical description is complicated by their complexity and the lack of information about a given stage of development and, even if it is possible, the mathematical model would be so complex and unwieldy that it would be difficult to use for calculations. Such complex processes include those of armed conflict, which are characterized by the mass use of the most diverse types of weapons and military equipment and the participation of vast numbers of people, the mathematical

description of the behavior of which, having regard to the psychological and moral factor, is at present an enormously difficult problem, toward whose solution we have taken only the first steps. Apart from this, as we have already indicated, heuristics is essential in the forecasting of processes subject to the actions of abrupt changes in the future. Such processes may include, for example, changes in the future characteristics of weapons and military equipment which occur when fundamentally new technical ideas and solutions are achieved. The advantages of heuristic forecasting are most fully manifested in the production of combined heuristic-mathematical forecasts, which will be considered in detail in chapter 8.

Thus, as follows from the foregoing, military affairs is a field in which heuristic forecasting has the widest applications.

NOTES

1. M. N. Tukhachevskiy, *Izbr. proizv.* [Selected Works] (Moscow: Voyenizdat, 1964), I, 141.
2. Lenin, XXXI, 134.
3. V. I. Lenin, *Soch.* [Works], V, 444.
4. M. V. Frunze, *Sobr. soch.* [Collected Works], III, 316.
5. Marx, Engels, I, 568.
6. Marx, Engels, XXII, 395.
7. M. V. Frunze, *Izbrannyye proizvedeniya* [Selected Works], 1934, p. 322.
8. K. A. Timiryazev, *Soch.* [Works], V, 321–22.

Chapter 7. Mathematical Forecasting

1. General Principles

Mathematical methods of investigation at the present time are widely used in military affairs in general and in military forecasting in particular. One of the factors which facilitates mathematical forecasting methods in military affairs is the availability of high-speed electronic computers with a large storage capacity.

There is now a well-constructed theory of forecasting stationary random sequences and processes. (Their probabilistic characteristics do not vary with any shift in the time of the arguments on which they depend [25], [41], [75].) This theory is used in the forecasting of, for example, the characteristics of signals of various electrical and radio systems, etc. Works dealing with certain aspects of forecasting nonstationary random processes include bibliography items [41] and [72]. In a number of branches of military affairs (for example, the forecasting of meteorological factors, the trajectories of guided and unguided ballistic missiles, etc.), some quite well-developed mathematical forecasting methods are in wide practical use.

In this chapter we shall dwell on the methodological questions and practice of mathematical forecasting, having arbitrarily subdivided the mathematical methods into the following groups:

—statistical forecasting methods (statistical extrapolation methods);
—mathematical modeling methods;
—mathematical methods of forecasting abrupt changes in the development of processes.

The principal assumption in using the first of these methods is that the process in the lead sector behaves in exactly the same way as it does in the observation sector (develops in accordance with one and the same law). In using the mathematical modeling method it is assumed that the model correctly describes the required properties and parameters of the

process which will occur in the future. The assumption that the model of the process being forecast will not vary in the future is dropped when using the third of the indicated methods (methods of forecasting abrupt changes in the development of a process).

2. Statistical Forecasting

The process of statistical forecasting consists in the processing by statistical methods of available data about the characteristics of the process being forecast, finding the dependency which relates these characteristics to time (and a number of other independent variables), and calculating by means of the found relationship the characteristics of the process at a given moment of time (for given values of other independent variables). In statistical forecasting, data which directly characterize a concrete, actually developing process are subjected to processing and subsequent extrapolation, as distinct from, for example, mathematical forecasting, considered in the following section, in which the forecasting data is obtained by means of calculations carried out on a mathematical model of the process being forecast.

In statistical forecasting the role of specialists in the object being forecast (for example, a particular model of a weapon) consists in:

—the preparation of initial data;
—the selection and justification of the form of extrapolation functions which relate the characteristic being forecast to time and a number of other independent variables;
—logical analysis of the forecasting results.

Only the most general recommendations (chapters 2–5) can be given concerning the preparation of initial data, the selection of the form of the extrapolation functions, and the analysis of the forecasting results, because the forecasting process is a research process and, owing to the wide variety of objects of forecasts, has its own important specific features in each actual case.

The strictly mathematical stage of statistical forecasting is that of processing statistical data for determining unknown parameters (coefficients) of extrapolation functions and the computation of point and interval forecasts. Unlike the preceding problems (solved by specialists in the subject of the forecast), statistical data processing methods and the calculation of forecasts can be unified and serve as instruments in the hands of designated specialists in the solution of forecasting problems with them. We shall dwell in somewhat more detail on the existing and most widely used methods of statistical data processing and cite some examples of the use of these methods.

The oldest and most widely used method at the present time is the least-squares method, which we have already discussed in chapter 2 in the section on criteria in forecasting.

Let us denote the extrapolation function (the deterministic base of the process being forecast) by $f(\bar{a}, \bar{x})$, where $\bar{a} = (a_1, a_2, \ldots, a_n)$ are certain coefficients, which are unknown a priori and have to be determined; $\bar{x} = (x_1, x_2, \ldots, x_n)$ are factors which influence the value of the process into which time t also enters.

In using the least squares method, estimates of the n unknown coefficients $\hat{a} = (\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_n)$ are found from the condition of the minimum of the sum of the squares of deviations:

$$S^2 = \min \sum_{j=1}^{N} [y_j - f(\bar{a}, \bar{x}_j)]^2 = \sum_{j=1}^{N} [y_j - f(\hat{a}, \bar{x}_j)]^2, \quad (1)$$

where N—the number of statistical points—is the number of points of observations of the process being forecast ($j = 1, 2, \ldots, N$). In those cases where the deterministic base is linear with respect to the unknown coefficients, while the process has the form

$$y = a_1x_1 + a_2x_2 + \ldots + a_nx_n + \eta(\bar{x}), \quad (2)$$

where $\eta(\bar{x})$ is a normally distributed random process with zero expected value and an a priori unknown variance, which reflects the influence of different kinds of uncertainties accompanying the development of the process being forecast ("interference"), an analytical solution of the forecasting problem is possible. If there is an increase in the number of observations N or complication of the form of the deterministic base of the process ($n>3$), calculation difficulties sharply increase. However, the problem of determining unknown coefficients and calculating point and interval forecasts can be successfully solved by the formation of an appropriate algorithm and the use of modern computers.

With the given form of the deterministic base of the process, the forecasting problem amounts to the use of information about N observed values of y_j ($j = 1, 2, \ldots, N$) in order to:

—estimate values of the unknown coefficients $\bar{a}$;

—estimate the mathematical expectation of the value of the process where $\bar{x} = \bar{x}_{fc}$ at a point of the forecast (point forecast) y_{fc};*

*[The Russian for 'forecast' begins with the same letters as the word for 'enemy,' and the two-letter Cyrillic subscript here is identical with the subscript used earlier in this book for enemy, which is identified in translation by 'e.' It would appear logical here that 'forecast' is intended in this context, but the reader is informed of this identity of abbreviations so that he may draw his own conclusions—U.S. Ed.]

—estimate the variance of the interference $D(\eta)$;
—construct a confidence interval (for a certain probability P, for example, $P = 0.95$ or $P = 0.997$) of the values of the process at a point of the forecast (interval forecast);
—make a mathematical assessment of the significance (degree of influence on y) of individual variables x_i and equation $f(\bar{a}, \bar{x}) = y$ as a whole.

In the present case we shall use the term "estimate" in place of "determine" or "calculate," in order to emphasize the fundamental impossibility of a precise determination or calculation of unknown coefficients $\bar{a}$ of the deterministic base $f(\bar{a}, \bar{x})$ in the presence of interference $\eta(\bar{x})$.

Estimates of unknown coefficients $\hat{a}$ for processes in the form of (2) can be determined from the expression [62]:

$$\hat{a} = (BB^{T})^{-1}B\bar{y}, \tag{3}$$

where

$\bar{y} = y_1, y_2, \ldots, y_N$ = a column of independent N observations (measurements) of process y being forecast;

$B = \|x_{ij}\|$ = an $(n \times N)$ matrix of values of independent variables $\bar{x}$ for different observations (element x_{ij} at the intersection of row i and column j denotes the value of the i component of x_i for observation j); the symbol "T" denotes the operation of matrix transposition; the symbol "-1" denotes the operation of its inversion [13].

It is known theoretically, [40], [50], that (for the assumptions made about the nature of interference) estimates (3) of unknown coefficients $\hat{a}_i$ $(i = 1, 2, \ldots, n)$:

—have a normal distribution;
—are not mixed, i.e., the expected value of estimates of $\hat{a}_i$ is equal to their true value of $\hat{a}_i$;
—are well founded, i.e., where there is an increase in the volume of statistics (an increase in N), estimates of $\hat{a}_i$ converge to values of coefficients of a_i;
—possess the minimal variance.

The mathematical expectation of the value of the process at a point of the forecast where $\bar{x} = \bar{x}_{fc}$ (point forecast) is determined from the

expression

$$\hat{y}(\bar{x}_{fc}) = \hat{a}_1 x_{1\,fc} + \hat{a}_2 x_{2\,fc} + \ldots + \hat{a}_n x_{n\,fc} = \sum_{i=1}^{n} \hat{a}_i x_{i\,fc}. \qquad (4)$$

Quantity $\hat{y}(\bar{x}_{fc})$ is an unmixed, well-founded estimate of the value of the process at a point of the forecast, is normally distributed, and has minimal variance.

An estimate of the variance of interference $\eta(\bar{x})$, determined from the expression

$$\hat{D}(\eta) = \frac{1}{N-n} \sum_{j=1}^{N} [y_j - (\hat{a}_1 x_{1j} + \hat{a}_2 x_{2j} + \ldots + \hat{a}_n x_{nj})]^2 = \frac{1}{N-n} \sum_{j=1}^{N} \left[y_j - \sum_{i=1}^{n} \hat{a}_i x_{ij} \right]^2, \qquad (5)$$

is an unmixed, well-founded estimate of the actual variance of interference $D(\eta)$. A forecast error δy_{fc} at point $\bar{x} = \bar{x}_{fc}$ can be characterized by the corresponding estimate:

$$\hat{D}(\delta y_{fc}) = \hat{D}(\eta)\,[1 + \bar{x}_{fc}^{T}(BB^{T})^{-1}\bar{x}_{fc}], \qquad (6)$$

which is an unmixed, well-founded estimate of the actual variance of the forecast error. The interval forecast of the future value of the process can be written in the form

$$\hat{y}(\bar{x}_{fc}) - t\sqrt{\hat{D}(\delta y_{fc})} < y_{fc} < \hat{y}(\bar{x}_{fc}) + t\sqrt{\hat{D}(\delta y_{fc})}, \qquad (7)$$

where t is a tabulated quantity, which depends on probability P, from which the confidence interval is formed, and on the type of distribution of the forecast error (in particular, for normal distribution where P = 0.997, t = 3) [5].

In a number of cases, where it is not known a priori how much the quantity being forecast is materially influenced by a particular parameter (x_i), a mathematical estimate can be made of the significance of the corresponding coefficients (a_i) and of the deterministic base as a whole. Physically, the insignificance of coefficient a_i denotes that the correspond-

ing parameter x_i from the point of view of the statistics at our disposal ($y_1, y_2, \ldots, y_N$) does not (with probability $P = 1 - q$) influence the quantity y being forecast and, therefore, can be excluded from the deterministic base.

The condition of the significance of coefficient a_i is written in the form

$$|a_i| > t_{q,\, N-n} \sqrt{\hat{D}(a_i)}, \tag{8}$$

where

$t_q, N-n$ = the tabulated q-percent limit for the Student distribution for values of $N-n>20$ normal distribution can be employed [5];

$\hat{D}(a_i)$ = the estimate of the variance of quantity $\hat{a}_i$, equal to the ith diagonal element of the matrix $(BB^T)^{-1}\,\hat{D}(\eta)$.

Condition (8) is equivalent to the hypothesis that $a_i \neq 0$. In estimating the significance of the deterministic base as a whole we verify the hypothesis that

$$f(\bar{a}, \bar{x}) = \sum_{i=1}^{n} a_i x_i = 0. \tag{9}$$

The insignificance condition of the base as a whole is written in the form

$$F \leqslant F_{q(N,\, N-n)}, \tag{10}$$

where

$F_{q(N,\, N-n)}$ = the tabulated Fisher distribution with N and $N-n$ degrees of freedom [5];

$$F = \frac{\frac{1}{N}\sum_{j=1}^{N} y_j^2}{\frac{1}{N-n}\sum_{j=1}^{N}\left(y_j - \sum_{i=1}^{n}\hat{a}_i x_{ij}\right)^2}. \tag{11}$$

A physical interpretation of the insignificance of a deterministic base may be as follows. Where equation (9) is fulfilled the variance of the process y being forecast is equal to the variance of interference $\eta(\bar{x})$, since

$$y = \eta(\bar{x}),$$

therefore verification of the insignificance of the base as a whole can be interpreted as verification of the hypothesis of the equality of the indicated variances. The dependences cited show that for processes in the form of (2) the forecasting problem and the determination of its errors can be resolved analytically. However, if there is an increase in the volume of statistics (an increase of N) and complication of the process model (an increase of n), the calculation difficulties sharply increase. These can be overcome by the creation of machine calculation algorithms (see, for example, bibliography item [62]).

Example 27. Under the conditions set forth in Example 3 we shall determine all the quantities enumerated above. The elements of expression (3) will take the form:

$$\bar{y} = \bar{C} = \begin{vmatrix} 490 \\ 1050 \\ 1600 \\ 1950 \end{vmatrix};$$

$$B = \| x_{ij} \| = \begin{Vmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \end{Vmatrix},$$

since in accordance with the accepted model $x_{1j} = 1$ and $x_{2j} = t_j$, whence

$$\hat{a} = \begin{vmatrix} \hat{a}_1 \\ \hat{a}_2 \end{vmatrix} = \left(\begin{Vmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \end{Vmatrix} \begin{Vmatrix} 1 & 1 \\ 1 & 2 \\ 1 & 3 \\ 1 & 4 \end{Vmatrix} \right)^{-1} \begin{Vmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \end{Vmatrix} \begin{vmatrix} 490 \\ 1050 \\ 1600 \\ 1950 \end{vmatrix} =$$

$$= \left(\begin{Vmatrix} 4 & 10 \\ 10 & 30 \end{Vmatrix} \right)^{-1} \begin{vmatrix} 5090 \\ 15190 \end{vmatrix} = \frac{1}{20} \begin{Vmatrix} 30 & -10 \\ -10 & 4 \end{Vmatrix} \begin{vmatrix} 5090 \\ 15190 \end{vmatrix} =$$

$$= \frac{1}{20} \begin{vmatrix} 800 \\ 9860 \end{vmatrix} = \begin{vmatrix} 40 \\ 493 \end{vmatrix}.$$

i.e., estimates of the unknown coefficients equal:

$$\hat{a}_1 = 40 \text{ rubles}, \hat{a}_2 = 493 \text{ rubles a year},$$

which corresponds to their values found by other means in Example 3.

A point forecast at points $t_{fc} = 5$ and $t_{fc} = 6$ in accordance with formula (4) is determined in the form:

$$\hat{C}_5 = 40 + 493 \cdot 5 = 2505 \text{ rubles}$$

$$\hat{C}_6 = 40 + 493 \cdot 6 = 2988 \text{ rubles}$$

In accordance with formula (5) the estimate of the variance of the interference equals

$$\hat{D}(\eta) = \frac{1}{4-2}[(490-533)^2 + (1050-1026)^2 +$$
$$+ (1600-1519)^2 + (1950-2012)^2] = 6440 \text{ rub.}^2.$$

In accordance with formula (6) the variance of the forecast error at point $t_{fc} = 6$ equals

$$\hat{D}(\delta C_6) = 6440\left(1 + \|1\ 6\| \begin{Vmatrix} 1.5 & -0.5 \\ -0.5 & 0.2 \end{Vmatrix} \begin{Vmatrix} 1 \\ 6 \end{Vmatrix}\right) =$$
$$= 6440\left(1 + \|1\ 6\| \begin{Vmatrix} (1.5-3) \\ (-0.5+1.2) \end{Vmatrix}\right) =$$
$$= 6440\,[1 + (-1.5 + 4.2)] = 6440\,(1 + 2.7) = 23800 \text{ rub.}^2.$$

An interval forecast with probability $P = 0.997$, reasoning from the assumption of a normal distribution law of the error $\delta\hat{C}_6$, is determined by formula (7)

$$2526 \text{ rub.} < C_6 < 3450 \text{ rub.}$$

Thus, according to a forecast with probability $P = 0.997$, the operating expenses for the motor vehicle in the sixth year will be found in the range

$$C_6 = 2988 \pm 462 \text{ rub.}$$

We shall cite an estimate of the significance of the coefficients and the deterministic base. Estimates of variances of coefficients equal to the diagonal elements of matrix $(BB^T)^{-1}\hat{D}(\eta)$ equal:

$$\hat{D}(a_1) = 6440 \cdot 1.5 = 9700 \text{ rub.}^2;$$
$$\hat{D}(a_2) = 6440 \cdot 0.2 = 1290 \text{ (rub/yr)}^2.$$

In accordance with the Student distribution table [5]

$$t_{q;\,N-n} = t_{5;\,2} = 4.3 \text{ and}$$
$$|\hat{a}_1| = 40 < 4.3 \cdot 98 = 420;$$
$$|\hat{a}_2| = 493 > 4.3 \cdot 36 = 155,$$

i.e., in accordance with formula (8) coefficient $\hat{a}_1$ with a probability of 0.95 can be considered insignificant and excluded, while coefficient $\hat{a}_2$ is significant, which confirms the assumption that the motor vehicle operating expenses increase linearly with time. Concerning the deterministic base as a whole, according to expression (11)

$$F = \frac{\frac{1}{4}(490^2 + 1050^2 + 1600^2 + 1950^2)}{6440} = 300;$$

according to the table [5] $F_{q\,(N,\,N-n)} = F_{5\,(4,\,2)} = 19.25$ and, consequently, since $F > F_{5\,(4,\,2)}$ according to expression (10), the deterministic base as a whole is significant.

Thus, as a result of calculations (for the given form of deterministic base of the process) we shall have point $\hat{y}\,(\bar{x}_{fc})$ and interval forecasts of the future value of the process:

$$\hat{y}\,(\bar{x}_{fc}) \pm t\sqrt{\hat{D}\,(y_{fc})}.$$

Processes of the type

$$y = a_1\varphi_1\,(\bar{x}) + a_2\varphi_2\,(\bar{x}) + \ldots + a_n\varphi n'\,(\bar{x}) + \eta\,(\bar{x}), \tag{12}$$

can be reduced to a process expressed by formula (2),

where

$\bar{x} = (x_1, x_2, \ldots, x_n)$ = as before, factors which influence the value of process y (arguments of the process);

$\varphi_i\,(\bar{x})\ (i = 1, \ldots, n')$ = certain known functions, which do not contain unknown coefficients, and which characterize the pattern of the effect of $\bar{x}$ on the quantity y being forecast.

Process (12) is reduced to the form of (2) by the replacement of variables $z_i = \varphi i\,(\bar{x})$. Sometimes we are faced with the problem of forecasting processes of the type:

$$y = a_0 a_1^{x_1} a_2^{x_2} \ldots a_n^{x_n} e^{\eta}, \tag{13}$$

$$y = a_0 x_1^{a_1} x_2^{a_2} \ldots x_n^{a_n} e^{\eta}, \tag{14}$$

which are reduced to the form of (2) by logarithmation.

Example 28. Let us consider an example of calculating estimates of unknown coefficients and forecasting the maximum thrust of liquid propellant rocket engines. Statistical data from bibliography item [73] are given in table 11. We shall forecast the evolutionary development of the thrust within the framework of a single principle. Let us select the period 1942 through 1953 as an observation interval and forecast for the years 1956–1963, so that it will be possible to make a comparison with the actual data. Of course, there is no real point in such an exercise. It merely serves to illustrate the method.

Since the example is simply for the purpose of illustration, we shall select, as the deterministic base of the process of variation of thrust in relation to time, a simple parabolic dependence, which is a particular case of a relationship of form (2):

$$f\,(\bar{a}, \bar{x}) = a_0 + a_1\,(t - 1941) + a_2\,(t - 1941)^2.$$

Calculations carried out in accordance with formula (3) resulted in the following estimate of the unknown coefficients:

$$\hat{a}_0 = 22.5\cdot 10^3;\quad \hat{a}_1 = -14.8\cdot 10^3;\quad \hat{a}_2 = 2.5\cdot 10^3.$$

The forecasting data and errors are given in table 11. From an analysis of these data it follows that the adopted form of the deterministic base gives a forecast in the evolutionary development sector (up to 1961) with a relative error of -12 percent in 1956 and 23 percent in 1960. Where there is an abrupt change (transition to system F in 1961), forecasting errors become unacceptably large (-51 percent in 1961 and -40 percent in 1963), which again characterizes the weakness of this particular statistical method of forecasting under conditions in which abrupt changes occur in the process being forecast, for this process does not conform to the hypothesis that there are no abrupt changes in the lead sector.

Example 29. Let us consider an example of a statistical method of forecasting the total weight of a helicopter, using data given in [73] and reproduced in table 12.

Using the statistics for 1947 through 1962, our task is to answer the questions, what will the total weight of the helicopter be

a) in 1963 with a payload of q = 2,400 lbs, a cruising speed V = 125 mph, and a range R = 313 miles?

b) in 1964 with corresponding characteristics: q = 8,000 lbs, V = 150 mph, R = 130 miles?

As a model of the deterministic base we shall select a dependence corresponding to the form of (14):

$$G = a_0 q^{a_1} V^{a_2} R^{a_3} (t - 1946)^{a_4}.$$

Calculations using the dependence and statistics for the period 1947 through 1962 quoted above resulted in the following estimates of the unknown coefficients a_i: a_0 = 1.14; a_1 = 0.59; a_2 = 0.73; a_3 = 0.20; a_4 = 0.21. The forecasting results and errors are given in table 12.

If we study this table, we can see that the resultant dependence will give helicopter weight forecasts with a relative error of 2 percent in 1963 and 13 percent in 1964.

In cases where the deterministic base of a process contains nonlinearly entering coefficients that require determination and cannot be reduced to linear form (2), for example,

$$f(\bar{a}, \bar{x}) = a_1 + a_2 e^{a_3 t} \sin a_4 t,$$

the forecasting problem, which involves the use of the least squares method cannot be solved analytically. In this case we can use a special search algorithm to find estimates of these coefficients and calculate a point and interval forecast using a computer [62].

Table 11.

Item	Year	Type	Thrust, lbs.	Forecast of thrust $\hat{Q}$, lbs.	Interval forecast	Forecast errors	
						$\hat{Q} - Q$	$\frac{1}{Q}(\hat{Q} - Q)$
Data for calculation of coefficients of model ("obsvn. intvl.")	1942	*AL* — 1000	1 000	—			—
	1943	*X35AL* — 6000	6 000	—			—
	1945	*CORPORAL* — *E* — *HW*	19 000	—			—
	1948	*XLR* — 10*RM* — 2	20 750	—			—
	1949	*XLR* — 59*AJ* — 1	90 000	—			—
	1952	*XLR* — 43*NA* — 3	120 000	—			—
	1953	*XLR* — 71*NA* — 1	240 000	—			—
Data for calculation of forecast error	1956	*XLR* — 83 — *NA* — 1	415 000	368 000	(158 000—577 000)	−47 000	−0.12
	1960	*XLR* — 109 — *NA*3	500 000	652 000	(208 000—1 095 000)	+152 000	+0.23
	1961	*F*1	1 500 000	735 000	(216 000—1 254 000)	−765 000	−0.51
	1963	*F*1*A*	1 522 000	917 000	(229 000—1 605 000)	−605 000	−0.40

Table 12.

Item	Year	Type	Payload q, lbs.	Cruise speed V, mph	Range R, miles	Gross weight, G, lbs.	Forecast weight, $\hat{G}$, lbs.	Forecast errors	
								absolute $\hat{G} - G$	relative $\frac{1}{G}(\hat{G} - G)$
Data for calculation of coefficients of model ("observation interval")	1947	UH-13	465	69	125	2 200	2 509	309	0.14
	1948	HH-43B	2 939	87	91	9 150	9 669	519	0.06
	1949	UH-19A	1 605	84	157	8 100	8 001	99	0.01
	1952	CH-21A	1 200	87	174	10 955	8 176	2 779	0.25
	1953	CH-21B	2 249	80	135	13 500	10 973	2 527	0.18
	1953	CH-37A	7 510	100	69	31 000	23 098	7 902	0.25
	1954	CH-34	3 980	85	145	13 000	16 802	3 802	0.29
	1956	UH-1A	800	101	72	5 864	6 696	832	0.14
	1958	CH-46	2 400	130	320	21 400	21 658	258	0.01
	1962	CH-47A	10 367	106	108	33 000	38 097	5 097	0.15
	1962	CH-54A	12 590	95	130	38 000	40 973	2 973	0.08
Data for calculation of forecast error	1963	CH-3C	2 400	125	313	22 050	22 576	526	0.02
	1964	CH-53A	8 000	150	130	39 713	44 752	5 039	0.13

The algorithm works as follows.

The investigator selects an initial value of the sought coefficients $\hat{a}_0 = (\hat{a}_{01}, \hat{a}_{02}, \ldots, \hat{a}_{0n})$. Then a computer is used to calculate the remaining sum of the squares of form (1), the gradient of this function $\frac{\partial S^2(\hat{a}_0,\bar{x})}{\partial \bar{a}}$ and takes a step (an increment $\Delta\hat{a}$ is given to coefficients $\hat{a}_0$) of a specific length in the direction opposite to the gradient. $S^2(\hat{a}_0 + \Delta\hat{a}, \bar{x})$ is calculated at a new point $(\hat{a}_0 + \Delta\hat{a})$ and compared with the preceding value. If there is a decrease in S^2 the operation is repeated. In this case $(\hat{a}_0 + \Delta\hat{a})$ is taken as the starting point. If during a given step there is no decrease of S^2, the length of the step is reduced. This process is continued until the decrease ceases (is not less than a certain predetermined limit). At this point the described method, known as the gradient method, is considered to have been fully exploited.

After this a further decrease of S^2 is sought by taking a random step to some "neighborhood" of the value of the sought coefficients, found by the gradient method, and S^2 is determined for new values of the coefficients. If this value is less than the previous one, we change over to the new values of the sought coefficients, otherwise we do not. If as a result of a number of similar random steps we succeed in establishing the direction of a further decrease of function S^2, the next steps are made in this direction, using the gradient method, until there is no further decrease in S^2 (in the sense indicated above). Random steps again are used to seek a new direction and, if it is not found, it is assumed that a certain local minimum has been achieved (where values $\hat{a} = \hat{a}_{\text{loc min}}$). The next operation is to verify this minimum for universality, since, unlike the case with linearly entering coefficients, which has a single minimum, in this case function S^2 can have several minima, and our task is to find the one with the greatest "depth."

To verify the universality of the found local minimum a random step is taken from point $\hat{a}_{\text{loc min}}$ to a sufficiently wide neighborhood of this point and a search is made by the method described above. If after several such steps have been taken, no local minimum has been found in which the value of S^2 is less than $S^2(\hat{a}_{\text{loc min}}, \bar{x})$, then $\hat{a}_{\text{loc min}}$ is assumed to be a value corresponding to the universal minimum and the search for coefficients is discontinued. If as a result of such operations a value $\hat{a}'_{\text{loc min}}$ is found at which

$$S^2(\hat{a}'_{\text{loc min}}, \bar{x}) < S^2(\hat{a}_{\text{loc min}}, \bar{x}),$$

then $\hat{a}'_{\text{loc min}}$ is taken as the new point of the local minimum and this in turn is analyzed for universality. The process is repeated until the uni-

versal minimum is found (the decrease of S^2 is less than a certain previously established threshold). The estimates of coefficients

$$\hat{a} = \hat{a}_{\text{univ min}}$$

found as a result of the described procedure are used to obtain a point forecast in accordance with the expression

$$\hat{y}(\bar{x}_{\text{fc}}) = f(\hat{a}_{\text{univ min}}, \bar{x}_{\text{fc}}).$$

It should be emphasized once again that the selection of a deterministic base, nonlinear with respect to the unknown coefficients, can be justified only if the investigator has sound physical grounds for this, otherwise this only complicates the forecasting process and increases the errors and the time taken to produce the forecast.

Example 30. Let us consider the problem of making a statistical forecast of the number of vessels of the U.S. Merchant Marine changing from sail to steam. The statistical data are given in table 13 [73].

An analysis of this process and an examination of the statistical data provide grounds for supposing that the deterministic base of the process of conversion can be described by an S-shaped logistic curve of the form

$$f(\bar{a}, t) = a + b\,\mathrm{th}\,(ct^* + d) = 50 + 50\,\mathrm{th}\,(ct^* + d),$$

for which is it assumed that $t^* = t - 1860$ (t is the current year), and coefficients $\hat{a} = \hat{b} = 50$ were taken for logical reasons, since the limit toward which the curve tends with an increase of t is equal to 100 percent.

The use of a special forecasting algorithm, which incorporates a block of estimates of coefficients nonlinearly entering into the deterministic base, and which operates in accordance with a scheme similar to that described above, makes it possible when using statistics prior to 1935 to obtain data and calculate the forecast errors given in table 13 [62].

Estimates of coefficients c and d equal $\hat{c} = 0.0336$, $\hat{d} = -1.005$, respectively.

The average relative forecast error is

$$\delta_{\text{av}} = \frac{1}{N}\sum_{l=1}^{N}\frac{\hat{y}_l - y_l}{y_l} = -\frac{1}{6}(0.02 + 0.02 + 0.01 + 0.01 + 0.01 + 0.01) = -0.013.$$

In figure 20 the forecasting dependence is represented by the solid line, and the statistical data, by dots.

Table 13.

Item	Year	Statistics y, %	Forecast $\hat{y}$, %	Forecast errors: absolute $\hat{y} - y$	Forecast errors: relative $\frac{1}{y}(\hat{y} - y)$
Data for calculation of coefficients of model ("observation interval")	1870	31.26	20.8	−10.46	−0.33
	1875	31.14	26.9	−4.24	−0.14
	1880	33.87	34.1	0.23	0.01
	1885	38.64	41.6	2.96	0.08
	1890	46.84	48.75	1.91	0.04
	1895	52.96	58.40	5.44	0.10
	1900	58.50	66.35	7.85	0.13
	1905	65.59	73.50	7.91	0.12
	1910	74.36	79.5	5.14	0.07
	1915	81.11	84.3	3.19	0.04
	1920	91.57	88.3	−3.27	−0.04
	1925	93.01	91.4	−1.61	−0.02
	1930	94.78	93.6	−1.18	−0.01
	1935	96.60	95.35	−1.25	−0.01
Data for calculation of forecast error	1940	98.26	96.6	−1.66	−0.02
	1945	99.62	97.5	−2.12	−0.02
	1950	99.71	98.3	−1.41	−0.01
	1955	99.85	98.7	−1.15	−0.01
	1960	99.90	99.1	−0.80	−0.01
	1965	99.95	99.4	−0.55	−0.01

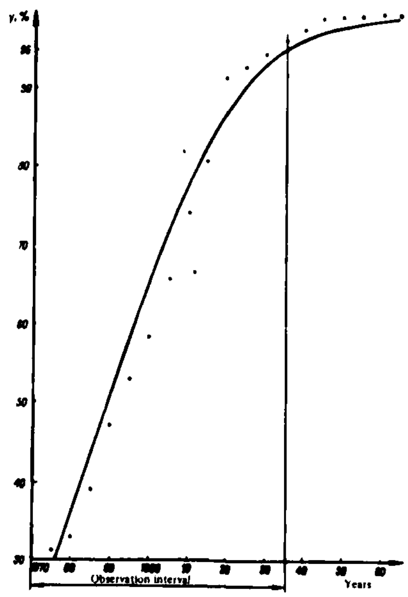


Figure 20. Example 30.

Example 31. Let us consider an example of the statistical forecasting of the maximum speed of military aircraft based on the data given in table 14 [73]. If we have grounds for assuming that the increase in the speed of aircraft proceeds in accordance with the expanded reproduction law with limited resources, then, as in the previous case, we shall take as the deterministic base a logistic curve

$$f(\bar{a}, t) = a + b\,th\,(ct^* + d),$$

where it is assumed that $t^* = t - 1900$ (t is the current year).

However, in this case (unlike the previous example) we shall consider all the coefficients to be unknown a priori.

The results of calculations of the forecasts and forecast errors according to statistics prior to 1956 are given in table 14.

The following estimates of coefficients were obtained:

$$\hat{a} = 1246. \quad \hat{b} = 1068. \quad \hat{c} = 0.084. \quad \hat{d} = -4.71.$$

The average relative forecast error is

$$\varepsilon_{av} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{\hat{V}_i - V_i}{V_i}\right| = \frac{1}{4}(0.01 + 0.08 + 0.07 + 0.06) = 0.06.$$

In figure 21 the forecasting dependence is represented by a solid line, and statistical data by dots.

Up to this point we have considered examples of the statistical forecasting of processes on the assumption that their models are invariable, both in the sector of observations of these processes and in the forecasting sector. In this case the calculated estimates of unknown coefficients of models enable us to obtain dependences which correspond uniformly well, from the point of view of the selected criterion (in this case, the criterion of the minimum sum of squares), to all the available data on the process. As new information is received about the process, the estimates are refined. In the light of this assumption, all information about the process (both current and old) is of identical value and is given the same weight in calculations. However, one cannot always be sure that the adopted model of the process will not vary. As we have already indicated, in the overwhelming majority of cases we are concerned with a process distorted by interference due to various kinds of uncertainties which accompany the process being forecast. In a number of cases it is extremely difficult to say whether a new observation (measurement) deviates from the expected because of the influence of the indicated interference, or as a result of a change in the model (a change in the nature of the occurrence of the process being forecast). If this deviation is caused by interference, the result of the new observation (measurement) should be considered as of equal value and complementary to the information

Table 14.

Item	Year	Type	Maximum speed V, mph	Forecast speed $\hat{V}$, mph	Forecast error $\hat{V} - V$	Relative forecast error $\frac{1}{V}(\hat{V} - V)$
Data for calculation of coefficients of model ("observation interval")	1909	Wright Bros. B	42	178	136	3.2
	1916	Curtiss JN=4	80	179	99	1.2
	1918	Nieuport 27C.1	110	181	71	0.65
	1918	Spad XIIIC.1	135	181	46	0.34
	1921	Boeing MB=3A	141	183	42	0.30
	1924	Curtiss PW=8	161	187	26	0.16
	1925	Curtiss P=1	163	189	26	0.16
	1927	Boeing PW=9C	158	193	35	0.22
	1929	Curtiss P=6	180	200	20	0.11
	1929	Boeing P=12	171	200	29	0.17
	1933	Boeing P=26A	234	221	−13	−0.06
	1934	Martin B=10B	212	228	16	0.08
	1937	Boeing YB=17	256	261	5	0.02
	1937	Seversky P=35	281	261	−20	−0.07
	1938	Curtiss P=36A	300	275	−25	−0.08
	1939	Curtiss P=40	357	292	−65	−0.18
	1940	North American B25	322	312	−10	−0.03
	1940	Bell P=39C	379	312	−67	−0.18
	1941	Martin B=26	315	335	20	0.06
	1941	Republic P=43	350	335	−15	−0.04
	1942	Republic P=47II	420	361	−59	−0.14
	1942	North American P51A	390	361	−29	−0.07
	1943	North American P51B	436	391	−45	−0.10
	1945	Lockheed P=80A	578	465	−113	−0.20
	1946	Republic XP=84A	619	509	−110	−0.18
	1948	North American F86A	671	615	−56	−0.08
	1950	Boeing B=47A	600	743	143	0.24
	1953	Convair F=102A	860	976	116	0.13
	1954	Mc Donnell F=101C	1200	1062	−138	−0.12
	1956	Convair B=58	1330	1240	−90	−0.07
Data for calculation of forecast error	1958	Lockheed F=104A	1404	1417	13	0.01
	1961	North American B=70	1800	1665	−135	−0.08
	1965	Lockheed SR=71	1800	1925	125	0.07
	1967	Convair F=111	1900	2021	121	0.06

already at hand. If, however, the deviation was due to a change in the model, the current information about the process will have the greatest value, and previous information obtained from observations of the process with an "old" model should be discarded or used with less weight

than the current data. In this case it is essential that the model permit current data about the process to be described as accurately as possible, and it is quite unnecessary that it should also accurately describe information obtained a long time ago. A variation in the model of a process can in some cases be predicted by experts. However, it is very important that a forecasting system which includes a particular mathematical system should be able to recognize these changes automatically.

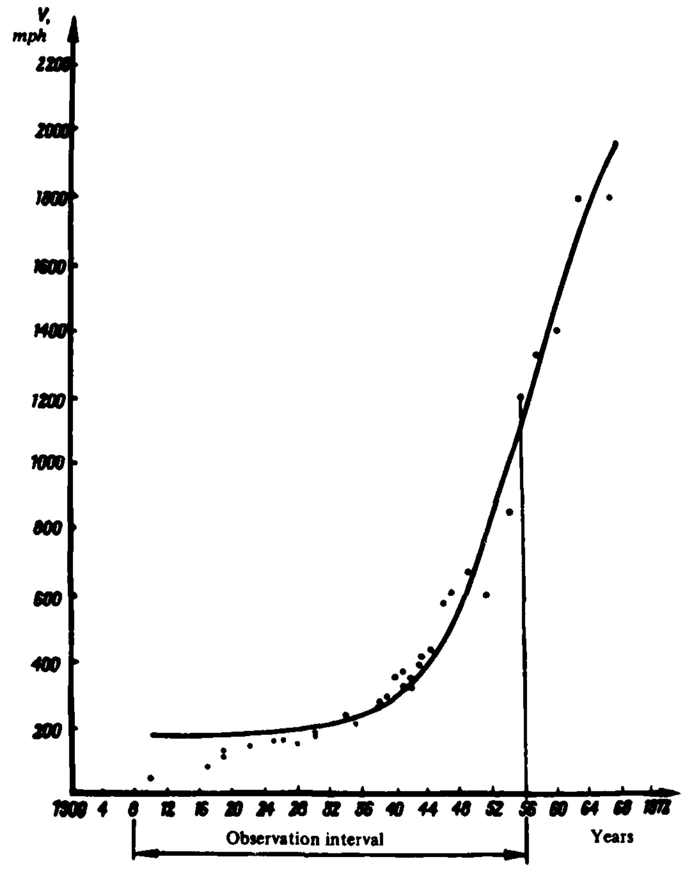


Figure 21. Example 31.

One of the ways of solving this problem is to use the method of the least "weighted" sum of squares. In utilizing this method, estimates of the unknown coefficients are found from the condition

$$\min \sum_{j=1}^{N} w_j^2 [y_j - f(\bar{a}, \bar{x}_j)]^2 = \sum_{j=1}^{N} w_j^2 [y_j - f(\hat{a}, \bar{x}_j)]^2, \quad (15)$$

where w_j^2 is the weight of the jth square of the difference between the measurement of the value of the process and its estimate.

The law of variation of the weight of the observations may vary within extremely wide limits. In particular, weight w_i^2 can be taken as decreasing with time in geometric progression, i.e., our "confidence" in the statistics decreases as the "age" of the data increases [70]. If one takes K of the last observations with a uniform weight $\frac{1}{K}$, and all the remainder with zero weight, we are dealing with the so-called moving average method. Where all the observations are of equal weight we have a particular case of the minimum "weighted" sum of squares method—the previously considered minimum sum of squares method. In general a decision about the selection of the method of estimating unknown coefficients of a model and calculation of the forecast values should be made in each specific case, proceeding from the forecasting problems and an analysis of the process being forecast. For example, under the conditions described in Example 29, if we are interested in forecasting the weight of helicopters with a large carrying capacity, then obviously, the statistical data relating to heavy helicopters can be used with greater weight than data about light helicopters.

In some cases it may prove expedient also to calculate data at the point of forecast with the corresponding weight.

The use of the minimum "weighted" sum of squares criterion (on the assumption of the possibility of a change in the coefficients of the model with time) permits us to simplify the form of the model of the deterministic base of the process being forecast.

Estimates of unknown coefficients $\hat{a}$ in the given case can be found from the expression

$$\hat{a} = \left(B W^2 B^T\right)^{-1} B W^2 \bar{y}, \qquad (16)$$

where
$W =$ a diagonal weight matrix of dimension $(N \times N)$, the element of which at the intersection of the ith line and the ith column, is w_i.

The remaining symbols are the same as in expression (3). Expression (16) is a "weighted" analog of expression (3), which is obtained from expression (16) as a particular case for $W = I$ (I is an identity matrix).

The point forecast is determined in accordance with expression (4).

Example 32. Let us determine under the conditions described in Example 3 estimates of the unknown coefficients of a model, assigning different weights to observations.

We shall construct a weight matrix in the form

$$W = \begin{Vmatrix} \beta^{3/2} & 0 & 0 & 0 \\ 0 & \beta & 0 & 0 \\ 0 & 0 & \beta^{1/2} & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix}$$

Here $\beta = 0.8<1$, which corresponds to an exponential decrease in the weight of the observations as their "age" increases.
Considering that

$$W^2 = \begin{Vmatrix} \beta^3 & 0 & 0 & 0 \\ 0 & \beta^2 & 0 & 0 \\ 0 & 0 & \beta & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix},$$

we obtain

$$\hat{a} = \begin{vmatrix} \hat{a}_1 \\ \hat{a}_2 \end{vmatrix} = \left(\begin{Vmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \end{Vmatrix} \begin{Vmatrix} \beta^3 & 0 & 0 & 0 \\ 0 & \beta^2 & 0 & 0 \\ 0 & 0 & \beta & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix} \begin{Vmatrix} 1 & 1 \\ 1 & 2 \\ 1 & 3 \\ 1 & 4 \end{Vmatrix} \right)^{-1} \times$$

$$\times \begin{Vmatrix} 1 & 1 & 1 & 1 \\ 1 & 2 & 3 & 4 \end{Vmatrix} \begin{Vmatrix} \beta^3 & 0 & 0 & 0 \\ 0 & \beta^2 & 0 & 0 \\ 0 & 0 & \beta & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix} \begin{vmatrix} 490 \\ 1050 \\ 1600 \\ 1950 \end{vmatrix} = \left(\begin{Vmatrix} 2.94 & 8.18 \\ 8.18 & 26.26 \end{Vmatrix} \right)^{-1} \begin{vmatrix} 4345 \\ 13225 \end{vmatrix} =$$

$$= \frac{1}{10} \begin{Vmatrix} 26.26 & -8.18 \\ -8.18 & 2.94 \end{Vmatrix} \begin{vmatrix} 4345 \\ 13225 \end{vmatrix} = \frac{1}{10} \begin{vmatrix} 5000 \\ 3500 \end{vmatrix} = \begin{vmatrix} 500 \\ 350 \end{vmatrix}.$$

i.e., for the given weight calculation the estimates of the unknown coefficients are:

$\hat{a}_1 = 500$ rubles per year;
$\hat{a}_2 = 350$ rubles per year.

A point forecast for the sixth year in accordance with expression (4) will be

$$\hat{C}_6 = 500 + 350 \cdot 6 = 2600 \text{ rubles}$$

Example 33. Let us forecast from statistics (Example 31), using the minimum "weighted" sum of squares criterion in accordance with the following form of deterministic base of the process:

$$f(\bar{a}, t) = a_0(t) + a_1(t)\, t.$$

Here the weight of the jth square of difference [see expression (15)], where $j = 0, 1, \ldots, N$ is taken from the last observation, was taken to be

$$w_j^2 = \beta^{\frac{N(t_N - t_{N-j})}{t_N - t_0}}$$

where t_N and t_0 are the moments of time of obtaining the Nth and initial observations, respectively;

N is the number of observations up to the present moment of time t_N, $\beta = 0.895 < 1$.

Actually, in finding the estimates of unknown coefficients from the condition of the minimum of functional (15), the weight coefficient of the current difference of squares (determined by the current observation, in which we have more "confidence" than in the others) at moment of time t_N for $j = 0$ is equal to $w_0^2 = \beta^0 = 1$, while the weight of the "oldest" difference of squares (at moment t_0) for $j = N$ is equal to $w_N^2 = 0.895^N < 1$.

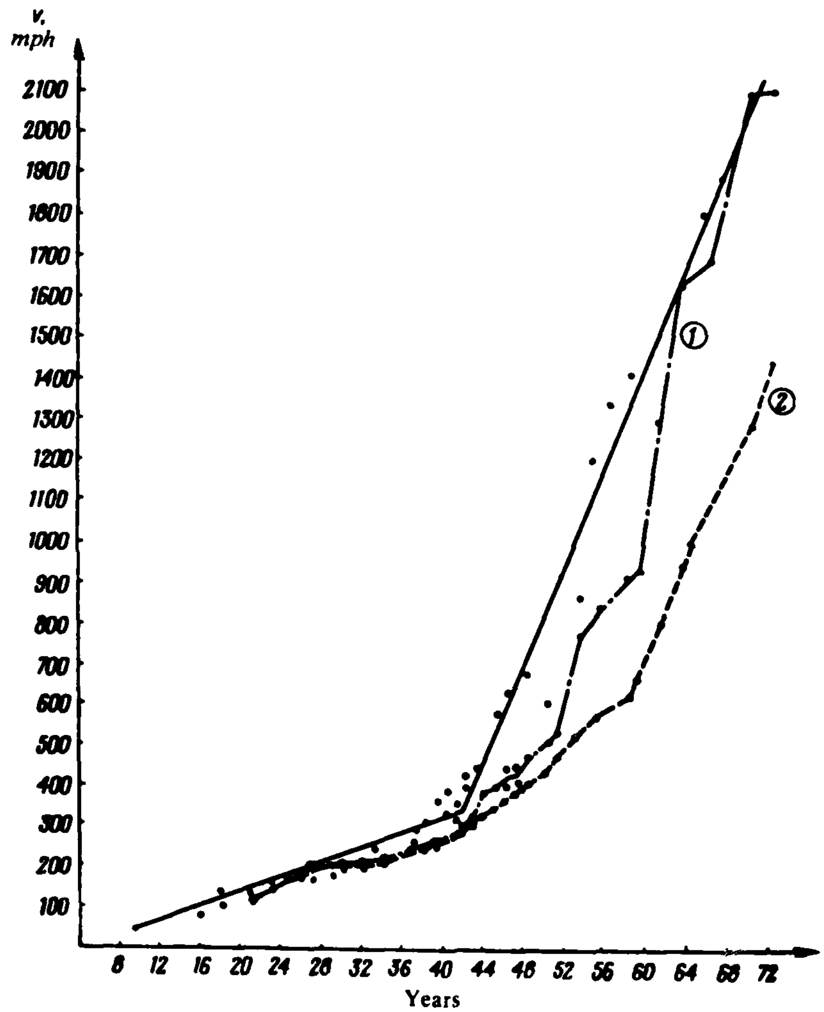


Figure 22. Example 33.

Five-year forecasts obtained with the use of a special algorithm are given in figure 22 (curve 1) [62]. Curve 2 represents the corresponding five year forecasts based on the use of the minimum sum of squares criterion conforming to a deterministic base:

$$f(\bar{a}, t) = a_0 + a_1 t.$$

A comparison of the curves shows that curve 1 "recognizes" more rapidly and traces an abrupt change in the coefficients of the model which occured in the 1940's and was determined by fundamental changes in engine configuration.

In conclusion, it is pointed out once more that the success of statistical forecasting depends primarily on the conformity of the form of the selected deterministic base to the actual development of the process, particularly in the lead interval. Therefore, the form of the deterministic base should be selected by experts on the basis of a thorough analysis of the nature of the process being studied. If there is sufficient information, certain components of this base can be selected by statistical methods using canonical expansions of random processes [41]. In cases where experts find it difficult to determine the best form of a deterministic base from a number of alternatives, they can resort to mathematical methods of selecting this base, using a number of mathematical criteria [62].

3. Mathematical Modeling

Before passing on to a description of mathematical modeling in military forecasting, we should point out that, as in the past, the principal method of forecasting in the investigation of problems relating to the military art, the theory and practice of conducting combat operations, the determination of the principal laws of armed conflict, and methods of controlling processes which accompany armed conflict, is the heuristic method, the main features and peculiarities of which were considered in the preceding chapter. Heuristic forecasting, along with physical modeling (exercises, games, etc.), is an effective method for gaining insight into methods of conducting combat operations in the future, the principles and methods of employment of new weapons and military equipment, troop command and control under new conditions, etc.

The method of investigation associated with the determination of quantitative characteristics of the laws of armed conflict involves the formation of mathematical models of combat operations by means of which forecasting problems can be solved. As we have said, mathematical modeling is highly effective for forecasting technical specifications of weapons and military equipment, since in this case forecasting is associated with well-studied laws of nature (the mechanics of rigid bodies, hydraulics, gas dynamics, etc.). The basis for the construction of mathematical models of combat operations is the study of the process of armed conflict. In this case the form and volume of the military-historical material to be studied is determined by the ultimate purpose of the research. For example, for studying the conditions of the cessation of combat operations (with victory or defeat) the indicated material should contain data about the initial and final resources of the sides, the duration and conditions governing the conduct of combat operations, etc. In con-

structing mathematical models of combat operations these data should be subjected to mathematical processing, in order to establish the quantitative relationships between different factors characterizing the aspect of the process of combat operations being studied. Here it should be noted that the capabilities of computer technology in the processing of large quantities of statistical data are considerably greater than those of the human mind.

The construction of mathematical models of combat operations involves the participation of individuals who specialize in the conduct and control of combat operations. Here, in the first stage of the construction of the model, a system of assumptions is introduced which reflects basic ideas about important aspects of a given process revealed during its study. The structure of the mathematical model is formed on the basis of these assumptions. The quality of the resultant mathematical model is verified by a thorough logical analysis of the results of modeling the process in question by means of this model. Such an analysis can be carried out only by specialists in the conduct and control of combat operations. Thus, it will be appreciated that these specialists play an extremely important role in forecasting by means of mathematical modeling.

Mathematical modeling in the hands of an investigator is a device for obtaining a quantitative estimate of the results of adopted decisions or the basis for the elaboration of such decisions. This is the basic purpose of mathematical modeling in forecasting.

Example 34. Let us examine an example of forecasting the course and outcome of a tank battle involving 50 tanks on each side, using the model quoted in Example 20. The rate of fire of the tanks on side I is $\lambda = 2$ rounds per minute, the probability of hitting a tank of side II with each shot fired by a tank of side I is $P = 0.5$. The corresponding characteristics of the enemy are: $\lambda_e = 5$ rounds per minute, $P_e = 0.3$.*

The solution of the system of equations taken from Example 20, for constant values of P, λ, P_e, λ_e for $n\,(t)$ has the form

$$n\,(t) = \frac{1}{2}\left[\left(n_0 - \frac{n_{0e}\sqrt{P_e\lambda_e}}{\sqrt{P\lambda}}\right)e^{\sqrt{P\lambda P_e\lambda_e}\,t} + \right.$$
$$\left. + \left(n_0 + \frac{n_{0e}\sqrt{P_e\lambda_e}}{\sqrt{P\lambda}}\right)e^{-\sqrt{P\lambda P_e\lambda_e}\,t}\right].$$

Because of the symmetry of the initial system of differential equations, a similar relation can be written for $n_e(t)$ also. The resultant relations of $n(t)$ and $n_e(t)$ enable us to forecast the change as related to time of the numerical strength of the opposing sides.

*[The Russian abbreviation referred to on p. 161 as being used for 'forecast' has now returned to its earlier use as 'enemy'—U.S. Ed.]

The time of the end of the battle (for example, on the complete destruction of side II) is determined from the condition $n_e(t) = 0$, whence, using the notation $\Phi = P\lambda n_0^2$ and $\Phi_e = P_e\lambda_e n_{0e}^2$ ($\Phi > \Phi_e$) we find

$$t_{\text{end}} = \frac{1}{\sqrt{PP_e\lambda\lambda_e}} \ln \sqrt{\frac{\sqrt{\Phi}+\sqrt{\Phi_e}}{\sqrt{\Phi}-\sqrt{\Phi_e}}}. \text{*}$$

The number of surviving units of the winning side in this case is determined by means of the formula

$$n_{\text{end}} = n_0 \sqrt{1-\frac{\Phi_e}{\Phi}}.$$

Returning to the numerical data of the example, we find

$$\Phi = 0.5\cdot 2\cdot 50^2 = 2500; \quad \Phi_e = 0.3\cdot 5\cdot 50^2 = 3750.$$

From the inequality $\Phi_e > \Phi$ it follows that victory will go to side II after a time (in minutes):

$$t_{\text{end}} = \frac{1}{\sqrt{0.5\cdot 0.3\cdot 2\cdot 5}} \ln \sqrt{\frac{\sqrt{2500}+\sqrt{3750}}{\sqrt{3750}-\sqrt{2500}}} = 1.3,\dagger$$

side II being left with

$$n_{\text{end}} = 50\sqrt{1-\frac{2500}{3750}} = 29 \text{ tanks.}$$

Thus, the demonstrated modeling of a battle between two groups of tanks (in the present case obtained analytically) shows that on the average, with the indicated initial data, victory goes to side II, which comes out of the battle after 1.3 minutes with 29 tanks.

Since such an analysis affords little comfort to side I, it is obvious that measures should be taken to ensure that the results of a future battle will be to its advantage. In particular, for the tank characteristics cited side I could count on victory only if it had a numerical superiority in tanks. The magnitude of this superiority can be found from the condition

$$\Phi > \Phi_e$$

*[The abbreviation for 'end' here is different in Russian from the one used earlier in the book—U.S. Ed.]

† Since firing is not continuous in real situations, the actual value of t_{end} will be considerably greater.

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or

$$\frac{n_0}{n_{0\,e}} > \sqrt{\frac{P_e \lambda_e}{P\lambda}} = \sqrt{\frac{0.3 \cdot 5}{0.5 \cdot 2}} = 1.23,$$

i.e., a superiority in tanks of at least 23 percent is required.

Thus, to achieve victory side I should have at least 13 additional tanks.

To achieve victory after a certain time not in excess of a certain t^*_{end}, side I will need a still greater number of tanks, which can be found from the condition

$$t_{end} = t^*_{end}$$

If, for example, $t^*_{end} = 2$ minutes, then

$$\frac{n_0}{n_{0\,e}} = \frac{\sqrt{P_e \lambda_e}}{\sqrt{P\lambda}} \cdot \frac{e^{2 t^*_{end} \sqrt{PP_e \lambda\lambda_e}} + 1}{e^{2 t^*_{end} \sqrt{PP_e \lambda\lambda_e}} - 1} = 1.25,$$

i.e., it is essential to have a superiority in tanks of at least 25 percent.

Working with a model, a result (point forecast) is obtained, based on known (determined) initial data. Modeling may also be useful in a case where the initial data are known with a certain degree of error, or in a statistical sense. In this case, of course, the result will, in a sense, be an "interval" forecast. For example, if it is known that the rate of fire of the enemy's tanks is four to six rounds per minute, the required degree of superiority in tanks of side I will, in the present case, be established within the limits

$$1.1 < \frac{n_0}{n_{0\,e}} < 1.35,$$

i.e., for the person making the decision, a certain data "bracket" will be given, the limits of which can be accurately stipulated (a 10 percent superiority is required if the enemy tanks have a rate of fire of four rounds per minute; a rate of fire of six rounds per minute necessitates a 35 percent superiority).

We have examined the simplest example of forecasting by a mathematical modeling method. Models based on dynamic equations of averages enable us to forecast more complex situations, in which different types of combat units participate on the two sides. Here we can take into consideration the possibility of simultaneous hits on several units, natural losses (wear and tear, breakdown due to defects, etc.), the commitment of reserves and the reconstitution of combat units, the influence of prehistory, etc. Of course, this means that the models are more complicated and modeling entails the use of computers. A forecast produced by means of such models represents the information required for the selection of the required number of weapons and the optimal target distribution.

Use of the space-time models referred to in chapter 4 makes it possible to select troop combat formations and the best means of troop command and control.

The general idea of modeling with these models is similar to that of modeling processes involved in the motion of such physical objects as artillery shells, ballistic missiles, etc., models of which were discussed in chapter 4. In both cases the process of modeling yields information about the variation with time (under the influence of control, interference, etc.) of the parameter which interests us (the number of jth type forces of a given belligerent, the coordinates of a missile, etc.). However, for describing combat operations there is a special class of probability models which do not operate with the average numbers of forces of the sides, but with the probabilities of weapon survival. The use of such models is based on the determination of the probability that, after a certain period of time, a given number of the total number of combat units involved will survive. An example of such a model for a duel situation is given in chapter 4.

Example 35. Let us consider an example of the use of this model for forecasting the respective probabilities of the survival of tanks, the hit probability and rate of fire of which are given in Example 34.

Since P and P_e are invariable, we have an analytical solution of the set of equations given in Example 17:

$$P_A(t) = 1 - \frac{\lambda_e P_e}{\lambda P + \lambda_e P_e}\left[1 - e^{-(\lambda P + \lambda_e P_e)t}\right];$$

$$P_B(t) = 1 - \frac{\lambda P}{\lambda P + \lambda_e P_e}\left[1 - e^{-(\lambda P + \lambda_e P_e)t}\right].$$

We find the probabilities of the states after one minute of battle:

$$P_A(1) = 1 - \frac{5 \cdot 0.3}{2 \cdot 0.5 + 5 \cdot 0.3}\left[1 - e^{-(2 \cdot 0.5 + 5 \cdot 0.3)1}\right] = 0.45;$$

$$P_B(1) = 1 - \frac{2 \cdot 0.5}{2 \cdot 0.5 + 5 \cdot 0.3}\left[1 - e^{-(2 \cdot 0.5 + 5 \cdot 0.3)1}\right] = 0.63.$$

We note that the maximum probabilities (where $t \to \infty$) are, respectively

$$P_A(\infty) = 1 - \frac{5 \cdot 0.3}{2 \cdot 0.5 + 5 \cdot 0.3} = 0.4;$$

$$P_B(\infty) = 1 - \frac{2 \cdot 0.3}{2 \cdot 0.5 + 5 \cdot 0.3} = 0.6.$$

Thus, the tank characteristics are such that, after 1 minute of combat, they are already close to their limit. In the theory of stochastic duels even more complex cases are considered in which there is more than one participant to a side, with limited and unlimited duel time, with and without taking into consideration shell flight time, etc. Forecasting results obtained

by modeling with probability models can be used for selecting the optimal tactics of small subunits. For example, it cannot be recommended that a tank of side A in the example we have just considered should engage in a duel for longer than 15–20 seconds, since up to that time the probability of its survival is still sufficiently high ($P_A \approx 0.70$), while at the end of the first minute it is reduced to 0.45. Another obvious way of increasing the probability of survival of a tank of side A is to increase its rate of fire λ. Actually by increasing the rate of fire by one round a minute ($\lambda = 3$) the probability of survival of a tank of side A at the end of the first minute of the battle is increased to $P_A(1) = 0.53$ (instead of 0.45 for $\lambda = 2$ rounds a minute), while the corresponding probability for a tank of side B is reduced to $P_B(1) = 0.52$ (instead of 0.63 for $\lambda = 2$ rounds a minute).

We have considered a very simple example which, nevertheless, shows that modeling with duel type probability models enables us to obtain interesting and useful results.

In a sense, similar problems are solved in calculations of probabilities using algebraic probability models, which characterize the probability of the occurrence of a particular event, depending on a number of parameters, which may include time. Thus, for example, by using the results of calculations of the distribution density of shell explosion points (Example 14) we are able to determine the number of shells needed to hit a particular target. And the use of a model which characterizes the probability of detecting an enemy radio signal (Example 15) enables us to obtain information needed to work out a watch schedule for an intelligence-gathering system.

In forecasting, wide use is made of modeling using queueing theory relationships.

Let us consider a forecasting problem using the queueing theory model given in Example 16.

Example 36. In order to make a decision about air defense organization, it is very important to calculate the number of aerial targets which will be able to penetrate an air defense system or unit.

Let us find the average quota of aerial targets which penetrate a given air defense system, if the flow of these targets is quite simple, with a density of $\lambda = 2$ aircraft a minute, while the system has $n = 4$ channels, each of which directs one means of air defense onto one aircraft, while the average guidance time $m_{t_f} = 2$ minutes. In this case it can be assumed that this is a fail-safe system, since if guidance is not commenced at the moment the aircraft enters the system's zone of coverage, the target is not fired on at all.

Let us solve a problem for the case of an established guidance process. Here the equations from Example 16 are simplified and we obtain

$$p_n(t \to \infty) = \frac{\dfrac{(\lambda m_{t_f})^n}{n!}}{\sum\limits_{k=0}^{n} \dfrac{(\lambda m_{t_f})^k}{k!}} = \frac{\dfrac{(2\cdot 2)^4}{4!}}{1 + 4 + \dfrac{4^2}{2!} + \dfrac{4^3}{3!} + \dfrac{4^4}{4!}} = 0.31.$$

Thus, on the average 31 percent of the targets pass through a given air defense system. The resultant figure and also figures for other raid variants enable one to determine when it is necessary to change the parameters of the indicated system.

In forecasting wide use is made of statistical modeling by the Monte Carlo method to estimate the influence of the tactics of use and the quantity and performance characteristics of weapons and military equipment on the results of a battle. Models which employ this method consist of a set of equations, rules, and relationships. As we have already indicated, the advantage of this method is that it imposes less rigid requirements on the description of the process from the point of view of its simplicity (complex functions, predetermined not only analytically, but from tables, may be used, and experimental data are introduced). The disadvantage of the method, which consists in the specific nature of the results of each individual modeling, is obviated to a certain extent, thanks to modern computers, which can perform a vast number of calculations in a very short time. An example of a description of a statistical model of the repulse of a tank attack was given in chapter 4. It is pointed out that statistical modeling can also be used for analyzing the battle results of other ground force subunits, the repulse of an enemy air raid by air defense facilities, etc. It should be noted that the statistical method of forecasting and forecasting with analytical models are interrelated. Thus, statistical modeling permits us to refine the form of the equations of analytical models and to determine certain parameters of these models. This interrelationship enables us to make the most of the advantages of models of each type. If the selection of the most effective features of a system involving the use of statistical modeling proves to be too work-intensive, statistical modeling is used for the construction of analytical models, the use of which provides information for the solution of various optimization problems.

4. Forecasting Abrupt Changes

Cases of abrupt changes in the development of a process are among the most complex problems in forecasting. From a mathematical point of view abrupt changes in the development of processes are associated with the concept of discontinuity in the function which characterizes the deterministic base of the process and/or its derivative. In practice we often encounter cases of continuous deterministic bases with discontinuity in the derivative (see, for example, figure 22). Such abrupt changes in the development of processes can be divided into two groups:

—after an abrupt change the qualitative relation between the parameters of the system is maintained—with an increase in one of them, the other increases (or decreases) as previously;

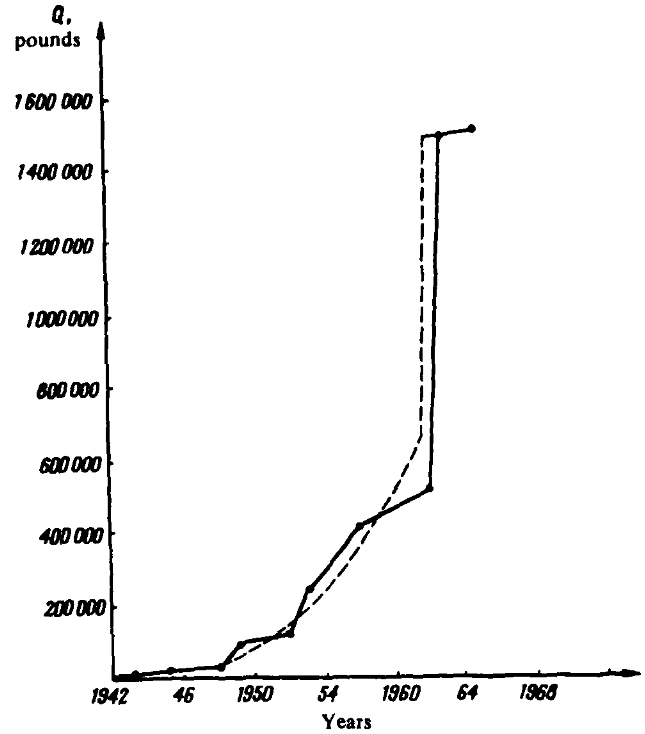


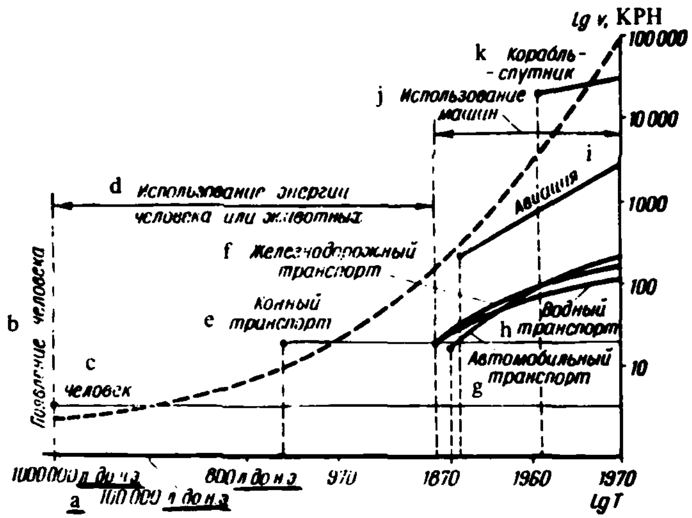
Figure 23. Change of Thrust Q of Liquid Propellant Rocket Engines as a Function of Time t.

—after an abrupt change the qualitative relation between the parameters which existed previously is disturbed.

Clearly, in the second case the forecasting of such processes presents particularly difficult problems.

Abrupt changes of the other type are discontinuities in the function which characterizes the deterministic base, similar to those shown in figure 23, for example, which was constructed on the basis of statistical data from table 11. Finally, there are abrupt changes which incorporate both types of discontinuities (see, for example, figure 24).

Abrupt changes in the development of processes are thus directly related to changes in their deterministic bases. In some cases the very form of the function characterizing this base changes. Here we are referring to fundamental changes in the development of processes, similar, for example, to changes in the military sphere associated with the creation of nuclear weapons. In other cases where the form of the determined base does not vary, abrupt changes occur in its parameters (coefficients). Thus, the change in the development of a process (figure 22) can be



Key:

a — BC (before Christ)
b — Appearance of Man
c — Man
d — Use of man or animal power
e — Horse transport
f — Rail transport
g — Motor transport
h — Water transport
i — Aviation
j — Use of machines
k — Orbital spacecraft

Figure 24. Change in Speed of Long-Distance Passenger Transportation as a Function of Time.

interpreted as an abrupt change in coefficient a_i of a linear model, and the change of engine thrust (figure 23) as an abrupt change in coefficient a_0 of a quadratic model.

A great many processes described by models of expanded reproduction undergo abrupt changes associated with changes in the reproduction constant. Figure 25 illustrates the time of transition from laboratory research to mass production, which is characterized by abrupt changes in the coefficient in the exponential index describing the deterministic base of this process. A considerable number of the processes are described by a function of the form

$$y = ax^b, \tag{17}$$

which characterizes the relationship between two (in the general case) dissimilar variables y and x. This relationship is called the law of uneven (allometric) growth. The discrete shift of the parameters (coefficients a and b) of this relationship leads to abrupt changes characteristic of a variety of processes of the most diverse nature. In particular, if we consider the change in the number of tanks in the former German Army as a function of the number of our tanks (figure 26), we see that an abrupt change takes place in the index of this relationship from positive to negative at the beginning of 1943. The mathematical study and description of processes is a most important prerequisite for the successful solution of an extremely wide range of problems, including forecasting problems.

It is interesting to note that Karl Marx in his day considered it feasible to apply mathematical methods to the study of such a complex social

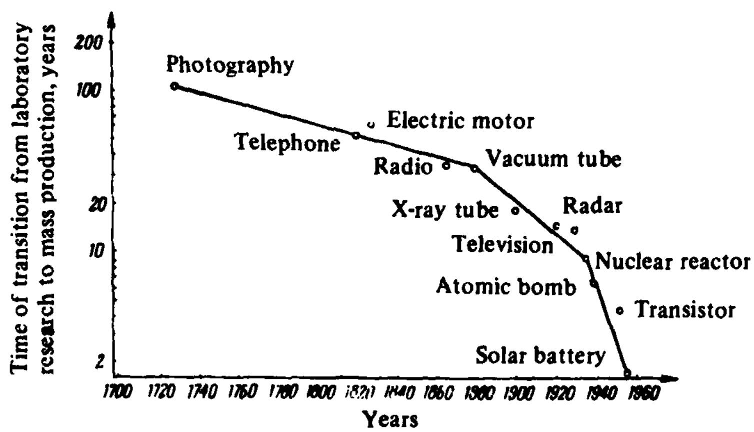


Figure 25. Transition From Laboratory Research to Mass Production of Various Devices as a Function of Time.

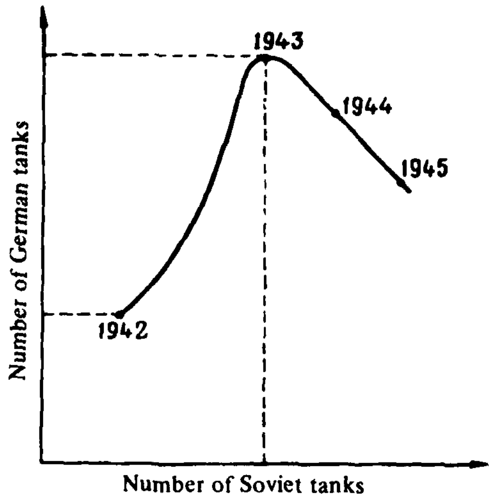


Figure 26. Number of German Tanks as a Function of the Number of Our Tanks.

phenomenon as economic crises of overproduction. In a letter to Engels he wrote: "I have repeatedly tried—for the purpose of analyzing crises—to figure out these ups and downs as incorrect curves and have thought (and even now think that with sufficiently verified material this is possible) of mathematically deriving from this the principal laws of crises."[1]

Forecasting abrupt changes in the development of processes is not only necessary but also, with the application of modern mathematical methods to a number of processes, practicable.

This is essentially a problem of determining the moment of time (or values of other parameters of the process) at which a change will take place in the nature of the development of the process, and of determining and describing the process after an abrupt change.

In the event that an abrupt change occurs at the present moment of time, it can be recognized by using the above-mentioned forecasting system, using the mathematical device of the "weighted" sum of squares (see Example 33). Forecasting the characteristics and consequences of a future abrupt change is a more complicated problem.

In principle an abrupt change in the development of a process can be viewed as a transition from one stable condition to another, due to the fact that the parameters of the system which determine the quantity being forecast have reached values at which the system in its former state becomes unstable. Therefore, the system, having abruptly changed certain parameters, is "forced" to switch to a new, stable region of evolutionary development. A natural mathematical device for forecasting ab-

1. Marx, Engels, XXXIII, 72.

rupt changes is seen in the qualitative methods of mathematical analysis, which make it possible to determine the areas of structural stability of a system and their limits.

In an earlier work about models of expanded reproduction, where the development of a process takes place in accordance with an exponential dependence, it is shown that, if delay of argument is taken into consideration, both the moments of time of an abrupt change in the reproduction constant and the magnitudes of this change can, in principle, be forecast [62]. Delay (time displacement) is brought into consideration because of the fact that in a number of cases the rate of increase of the given quantity is proportional, not to the quantity itself at the present moment of time, but to the value of this quantity at a moment of time displaced from the present moment by a certain interval τ. For example, in forecasting the output of a certain sector of industry, the role of such a time displacement is played by the times taken in construction of plants belonging to this sector.

The reproduction constant at high rates depends on τ (figure 27) and varies in an area bounded by two hyperbolas:

$$a = \frac{1}{\tau} \text{ and } a = \frac{c}{\tau}$$

(c is a constant depending on the type of process and having a magnitude of the order of 0.6–0.8).

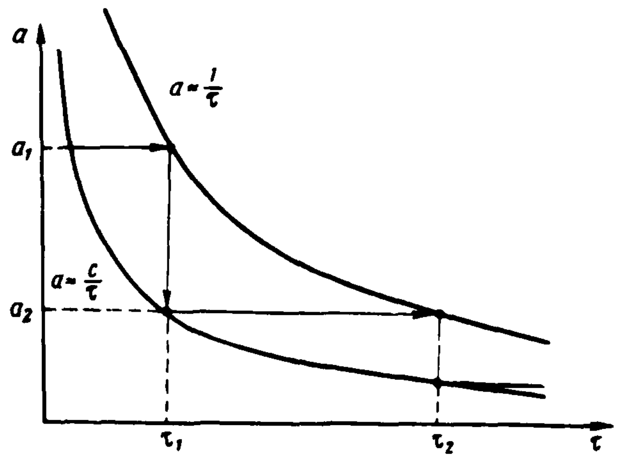


Figure 27. Explanation of a Method of Forecasting Abrupt Changes.

If a process develops with a specific reproduction constant (for example, a_1), then on approaching the limit $a = \frac{1}{\tau}$ (for $\tau = \tau_1$) it enters a

zone of unstable fluctuations of the most varied frequencies. The system can be provided with a reserve of stability by a change in a—for one and the same τ the maximum reserve of stability in a high rate zone will be during transition to the limit $a = \frac{c}{t}$ (for $a = a_2$), where all variations, apart from those of one of the frequencies, will be attenuated. The process can then develop with a reproduction constant a_2 until it reaches τ_2, where the next abrupt change occurs, and so on. Consequently, knowing the variation of $\tau(t)$—for example, knowing from technical standards the construction periods for plants of a given size in a given year, information about which is more stable in a statistical sense than, let us say, information about the future output of a given sector—we can determine both the new quantity of the reproduction constant and the time of its abrupt change (figure 28). In observation interval $t_0 \leq t \leq t'$ we estimate the value of reproduction constant a_0 (for example, by the least squares method).

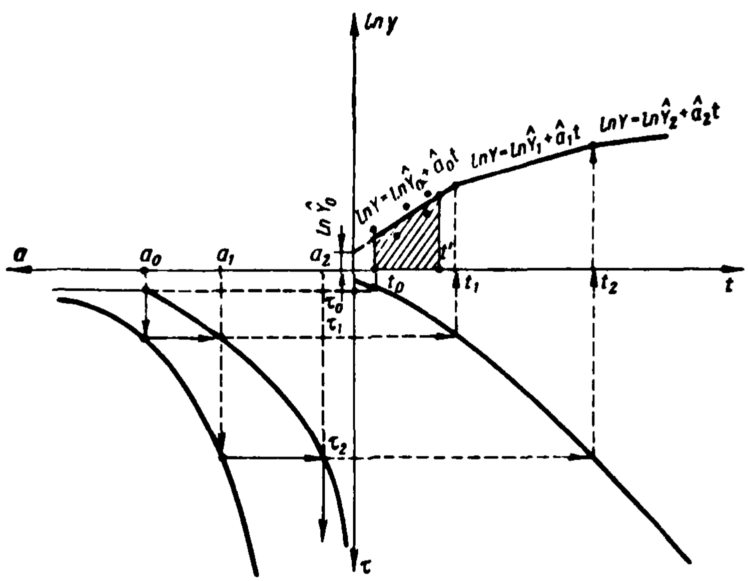


Figure 28. Illustration of a System of Forecasting Abrupt Changes.

Then we construct a curve showing the change of the reproduction constant depending on τ, and given the $\tau(t)$ relationship, we can forecast the deterministic base

$$\ln y = f(t).$$

It has been established that in analyzing a displacement of variable x analogous according to the terms of displacement of τ, abrupt changes in allometric relationships can also be forecast [62].

The above-mentioned exponential and allometric relationships by no means exhaust the entire range of diverse processes subject to abrupt changes; however, questions relating to the forecasting of processes described by these relationships will, from a methodological point of view, provide a useful contribution to the development of work on the mathematical forecasting of abrupt changes.

5. Errors and Fields of Application of Mathematical Methods

An examination of the mathematical methods of forecasting reveals three principal sources of error.

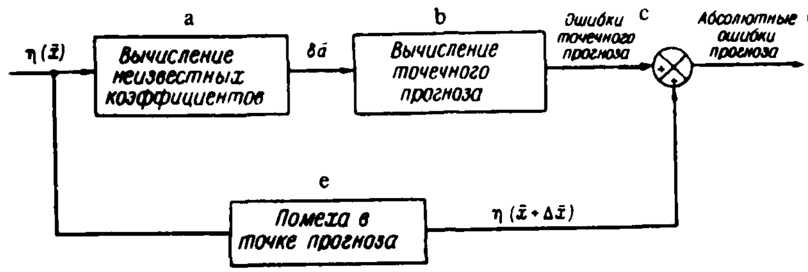
The first source of forecasting errors, which inherently makes forecasting a complex scientific research process, is the presence of uncertainties ("interference"), which distorts observed values of the process being forecast (in the observation sector), as well as possible values in the future (in the lead sector).

The second source of error is incorrect selection of the mathematical model of the process to be forecast, and, in particular, its deterministic base.

The third source of error is variation in the nature of occurrence of the process being forecast (abrupt changes in the development of the process) as compared with the initial state of affairs in the observation interval and particularly in the lead interval.

The first of the sources of error enumerated above is common to all methods of forecasting (including mathematical methods). The presence of uncertainties, as we have already remarked, is the *raison d'être* of forecasting problems, and to a large extent determines the second and third sources of error.

Let us trace the course of the effect of the first source on forecasting errors using the example of statistical forecasting. We can reduce the uncertainties which accompany the process being forecast to a matter of the presence of random interference η in the mathematical model of the process. The presence of interference in the observation interval, even when the form of the deterministic base of the process has been correctly selected, results in errors in the evaluation of the unknown coefficients of this base. These errors are greater, the higher the level of uncertainty (intensity of interference) and the smaller the observation interval (the smaller the number of statistical points). Apart from this, the accuracy of estimation of the coefficients is influenced by the distribution of the



Key:

a - Calculation of unknown coefficients
b - Calculation of point forecast
c - Point forecast errors
d - Absolute forecast errors
e - Interference at point of forecast

Figure 29. Diagram Showing Formation of Forecast Errors.

statistics in the observation interval. Where the statistics are distributed at the ends of the observation interval the errors in evaluating the coefficients are, generally speaking, smaller. Errors in estimating coefficients are, in turn, the cause of errors in determining the value of the deterministic base at a point of the forecast (point forecast errors). Point forecast errors depend both on the magnitudes of errors in estimates of coefficients, and on the form of the deterministic base and the length of the lead interval—see expression (6). This dependence is governed by the fact that a point forecast is calculated in the form

$$y_{\text{fc}} = f(\bar{a} + \delta\bar{a},\ \bar{x} + \Delta\bar{x}),$$

i.e., errors in estimating coefficients $\delta\bar{a}$ are "carried over" to the point being forecast $\bar{x} + \Delta\bar{x}$ ($\Delta\bar{x}$ is the lead interval) through operation f. With an increase in the lead interval $\Delta\bar{x}$ point forecast errors have a tendency to increase.

Absolute forecast errors, apart from point forecast errors, will be determined additionally by the presence of interference at the point of forecast. In a statistical sense absolute forecast errors (the difference between actual future values of the process and the point forecast) will be greater than point forecast errors.

The manner in which forecast errors are formed is shown in figure 29.

Means of countering the first source of forecast errors include a detailed analysis of the statistics used for forecasting by experts on the subject under investigation in order to "purify" the statistics (exclude

information which does not relate to the process being forecast) and the use of well-tried methods of evaluating unknown parameters (coefficients) of mathematical models.

Theoretically, the second source of errors (incorrect selection of the mathematical model) precludes an accurate forecast, however accurate the calculations. The principal means of countering it is to enlist the help of highly qualified experts to elaborate a mathematical model of the process being forecast and conduct a logical analysis of the forecasting results. Theoretically, it is mathematically possible to recognize the "best" deterministic base of the process being forecast among a number of alternatives, which also makes it possible to reduce the influence of the second source of errors on forecasts [62].

The most dangerous is the third source of errors, which originates during the course of a given process as a result of a change in its initially (even though correctly) selected model. If these changes begin in the observation sector, they can in some cases be recognized in time with the required precision by means of the mathematical device of estimating the unknown coefficients of the deterministic base, utilizing the criterion of the minimum "weighted" sum of squares. If these changes occur in the lead sector, then the statistical and mathematical modeling methods in question will be ineffective in diminishing the forecast errors which arise in this case. For a certain class of processes, however, the indicated changes can in theory be forecast mathematically (see the previous section). However, the principal means of countering the third source of errors is at present the experience of the investigator and verification of the heuristics (the compilation of combined heuristic-mathematical forecasts).

Thus, an examination of mathematical methods of forecasting points to the conclusion that they are an objective and convenient (when computerized) means of compiling a forecast and, with a correctly selected mathematical model of the process, ensure the required degree of forecasting accuracy.

The most accurate of these are the mathematical modeling methods, since, as a rule, they employ models verified in practice, based on the use of well-studied laws of nature that govern the development of the process to be forecast. Here the chief task of the experts in the subject of the forecast, which essentially determines the success of forecasting, is the selection and justification of the model, and, in addition to this, the preparation and analysis of the initial data for modeling (initial conditions, various kinds of external influences, etc.).

In cases where, at a given stage of the investigations, there is no possibility of gaining a deep insight into the physical nature of the process

being forecast, though there is statistical information about how this process has developed up to the present time, we can use statistical methods of forecasting (mathematical extrapolation methods), which make it possible to forecast the future trend of a change in the process being forecast—a change in some generalized characteristic of the process (its mathematical expectation). In utilizing a mathematical extrapolation method, experts in the subject under investigation are required to provide information about those known factors (including time) which can influence the development of the process being forecast, as well as information about the possible relationship of these factors to the quantity being forecast. Subsequent forecasting is carried out by experts in mathematical extrapolation, whose tasks are to find the best (in some sense) agreement between the form of the mathematical description of the trend of development of the quantity being forecast and available statistics, calculate the forecast, and estimate its possible error. The basic assumption in mathematical forecasting is the invariability of the nature of the influence of various nonrandom and random factors on the characteristic being investigated, both in the past and present and in the future. This assumption fundamentally limits the field of application of "purely" mathematical methods of forecasting (particularly statistical forecasting). However, the use of mathematical methods in combined forecasting, including heuristic forecasting and logical analysis, is very promising. We shall dwell in more detail on combined methods of forecasting in the next chapter. At this point it is emphasized once again that the forecasting process is in each specific case an independent scientific research process, which can only be carried out with the participation of highly qualified experts in the subject under investigation. Here mathematical forecasting methods are unique instruments in the hands of these experts.

Chapter 8. Combined Forecasting

1. General Principles

Combined forecasts can be achieved by putting together information obtained by various exclusively mathematical methods as well as that obtained by the joint use of mathematical and heuristic methods. Combined mathematical forecasts can be made by the joint processing of forecasting results (of point and interval forecasts) obtained by various mathematical methods (for example, by statistical extrapolation and mathematical modeling) and by the use of different stages in the calculation of the forecast results (for example, the use of extrapolation data for mathematical modeling or the use of statistical forecasting data as input information for mathematical forecasting of abrupt changes). Although in a number of cases producing combined mathematical forecasts makes it possible to increase the accuracy of the forecast and is sometimes the only means of carrying out the task assigned, it does not ensure the complete eradication of the influence of the shortcomings inherent in mathematical forecasting methods on the forecasting results.

In a combined forecast based on heuristic and mathematical forecasting methods (heuristic-mathematical forecasts) we are able to combine the advantages of these methods and considerably reduce the influence of their shortcomings on the forecasting result.

In the simplest case combination consists in the use of data obtained from experts as input information for mathematical modeling. For example, in modeling combat operations with mathematical models, a number of parameters of these models, and the initial conditions as well, can be determined by the appropriate specialists (operators). Conversely, the results of mathematical modeling can be used as information for specialists engaged in heuristic forecasting.

A combined heuristic-mathematical forecast can be produced by jointly processing the results of heuristic and mathematical forecasting. We shall say more about methodological questions and the practical side of compiling such a forecast in subsequent sections of this chapter.

As already indicated, logical analysis, which we shall also consider in somewhat more detail, occupies an important place in many of the stages of the research process of forecasting.

2. Logical Analysis in Forecasting

Logical analysis is a process based on the laws of formal logic. It is mainly heuristic, but it can also be done by mathematical methods.

Logical analysis is a process of ascertaining and eliminating contradictions which arise during the research process of forecasting to ensure that its results and recommendations do not contradict currently established theoretical principles and common sense. In logical analysis wide use is made of the method of analogy: analogies of processes similar in physical properties and composition; analogies of the same processes, but occurring under different conditions (for example, foreign experience); comparison of processes occurring in parallel (for example, the process of the development of offensive and defensive weapons), taking into account their interrelationship. In logical analysis the process being forecast is broken down into parts and analyzed.

Logical analysis may yield data which are extremely valuable to the investigator.

In a number of cases it is possible to establish the possible range of variation of given quantities. For example, analysis of gas dynamics relationships which describe the movement of propellant gases behind a shell enables us to establish the maximum speed of an artillery shell to be fired from the barrel of a gun. Analysis of chemical elements with the simultaneous use of mathematics for forming all the possible combinations enables us to establish the maximum caloricities of chemical fuels.

In some cases logical analysis makes it possible to predict the trend of development of certain processes. Thus, for example, the results of forecasting the development of aerial attack weapons makes it possible to use logical analysis to predict the trend of development of air defense weapons. Example 24 above shows that the tendency of the speed of civil transport aircraft to increase with time can be determined from data on the variation in speed of military aircraft of the corresponding class.

By logical analysis we can establish the fact of the prevalence of one process over another in the future. For example, in such and such a year the production of semiconductor computers will be less than that of integrated circuit computers. Independent forecasting of each of these two processes and comparison and analysis of the results make it possible

to reduce forecast error. By logical analysis we can uncover discrepancies in particular forecasts on the basis of information about the fact that, for example, a certain quantity cannot go beyond certain limits: a certain quantity is known to be greater than zero or greater or less than some other specified quantity.

Logical analysis plays a particularly important role in the forecasting of processes subject to abrupt changes. Thus, by logical analysis we can foresee the beginning of the realization of a new technical idea and its consequences, i.e., stopping production of technical devices of an old type and starting production of new models. Logical analysis occupies an important place in the formation of the "target tree," the "tree of relative importance" of certain parameters, encountered in forecasting complex processes with a hierarchical structure. For example, if the time of completion of a certain event is being forecast, then, having constructed a "target tree" by means of mathematical and/or heuristic methods, the times of realization of the events in each "branch" and the total time are estimated. Here we have a combination of mathematics and heuristics. We can proceed similarly in forecasting the fact of the completion of a certain event or its probability. In this case the outcome of an event (occurred—did not occur) or the probability of its accomplishment in a given time is ascribed to the branches of the tree.

Example 37. As an example of a "target tree" we shall give the tree used in the PATTERN system (figure 30) [33]. This hierarchical "target tree" was constructed for estimating the relative importance of all the elements making up the PATTERN system. It was constructed on a logical basis by specialists, proceeding from a scenario in stages, level by level, so that the measures of the following level secured the objectives of the previous one. Naturally, on changing from general political to scientific and then technical problems, different specialists were called upon.

Various semiempirical and empirical relations can be widely used in logical analysis. For example, formulas for the utilization factor of the metal of artillery guns, the form factor of projectiles, the specific power of engines, etc.

Example 38. As an example of the use of logical analysis in depth we can cite the process of the exposure by the Russian Command of an important forged document put out by the German General Staff prior to World War I [46]. The Germans, through their agents, planted in the Russian General Staff a photocopy of a false "Memorandum on the Distribution of German Combat Forces in the Event of War." This was a distortion of Schlieffen's plan, adopted by the German General Staff, based on the idea of defeating first France, against which seven armies were deployed, then Russia, against which at first only one army would operate. The main thrust in the West was to be through Belgium, whose neutrality would be violated. In the false Memorandum, the main points of this plan were presented in the following form: "The war on three fronts is to be waged as follows: four armies on the French frontier, one army on the coast, three armies on the Russian frontier [46]." The Memorandum was intended to convince the Russians and the French that approximately equal forces would be arrayed against them and that the main thrust in the West would be made not by the right, but the left flank.

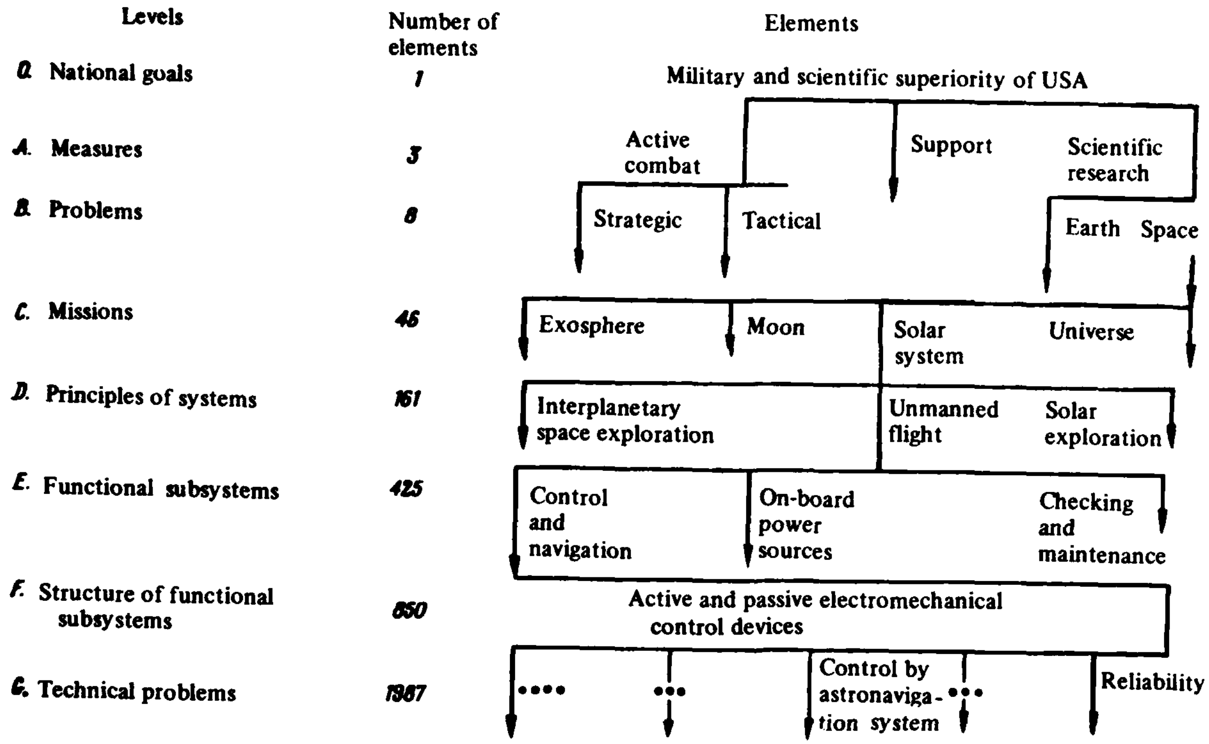


Figure 30. Hierarchical Structure of PATTERN "Target Tree."

The Memorandum was analyzed very carefully at the Russian General Staff Headquarters by Colonel V. Ye. Skalon, who brilliantly handled the task entrusted to him, although it entailed several months of tense and painstaking work, consisting of in-depth analysis of the clauses of the Memorandum, their comparison with available data, particularly on the strategic deployment of the Austrian armies. To answer the question of the most likely concentration of the German Armed Forces, Skalon put himself in the place of the enemy and tried to find the most expedient solution from the enemy's point of view. The results of his work were embodied in a document entitled "Notes on the Most Probable Concentration of the German Armed Forces on the Russian Frontier," in which it was not only proved that the Memorandum was a fake, but a forecast was made of the enemy's main operational-strategic plan.

In the "Notes" it was indicated that "the main body of the German forces would be allocated to fight the French armies" and that Germany would violate Belgium's neutrality, because "German troops passing through Belgium would move out into a wide envelopment of the French main defense line and on to the shortest routes to Paris." Thus, long before the beginning of the war (in 1900) the Russian General Staff had uncovered the enemy's strategic deployment plan.

Example 39. Let us consider an example of the use of logical analysis in solving combat problems associated with the combat operations of naval forces.

In resolving a question about the necessity of modifying the design of a ship, its armament and personnel requirements, it is frequently very important to estimate the losses sustained through damage or loss of the ship.

In bibliography item [37] an example of an investigation is given, the purpose of which was to determine the effectiveness of damage inflicted on British cruisers during World War II, as a result of enemy naval gunfire, aircraft bombing attacks, torpedo attacks, and mine explosions, for the purpose of putting forward recommendations for the most effective system of cruiser defense. In the investigation the effectiveness of the damage was defined as the number of months needed to repair and bring a cruiser back into service. The maximum loss was estimated at 36 cruiser-months, i.e., the time required for the construction of a new cruiser in place of one that had been sunk. The statistical data are given in table 15.

An examination of the data given in the table shows that more than half of the cruiser casualties (out of the total number of cases of cruisers sunk or damaged) were caused by aircraft bombing attacks. Therefore, at first sight it seems that the main problem was to improve the ships' air defense systems. However, a more detailed analysis shows that the number of cruiser-months lost when a cruiser was put out of action was highest as a result of torpedo attacks, since the damage sustained in this case was three times more serious than, for example, as a result of bombing. Moreover, a study of the damage resulting from bombing attacks shows that the majority of cruisers sunk in this fashion sustained damage below the waterline as a result of the explosion of bombs dropped in the immediate vicinity of the ship.

Thus, more than half of the lost cruiser-months was due to underwater damage of the ships' hulls. Therefore, it could be concluded that the underwater part of new cruisers should have better protection.

Table 15.

Type of damage sustained	Weapons used to inflict damage				Total
	Shells	Bombs	Mines	Torpedoes	
Cruisers sunk	3	9	1	11	24
Cruisers damaged	18	56	9	19	102
Total number of cruisers put out of action	21	65	10	30	126
Cruiser-months lost:					
As a result of sinking	110	320	40	400	870
As a result of damage	30	90	60	180	360
Total	140	410	100	580	1230
Percentage	11	34	8	47	100
Lost cruiser-months accounted for by each case of a cruiser being put out of action	7	6	10	19	10

3. Combined Use of the Results of Heuristic and Mathematical Forecasting

In certain cases it is necessary to use a combined heuristic-mathematical forecast based on the results of heuristic and mathematical forecasting. For example, if we are forecasting the processes of production, and the development of science and technology for a sufficiently long period (10 years or more), when there is a probability of abrupt changes appearing in the lead sector, mathematical methods of forecasting should be backed up by logical analysis and heuristic forecasting. In general terms the method of combined heuristic-mathematical forecasting may be as follows. On the basis of a physical analysis of the process being forecast by the appropriate specialists, we establish a mathematical model of the process being forecast and those values of parameters which may not be known. These parameters (coefficients) are determined on the basis of available statistics about the given process by mathematical (statistical) methods and a mathematical forecast is computed.

Heuristic forecasting is carried out independently of mathematical forecasting. The forecasting data are compared from the point of view of determining their "contradictoriness," and if they are found to be "noncontradictory," they are processed jointly to obtain a generalized combined forecast, which, in a statistical sense, possesses greater accuracy than its component (mathematical and heuristic) forecasts. If the forecasts are "contradictory," it is necessary to establish which of them is at fault. For this purpose we can use logical analysis and mathematical methods. If the mathematical forecast is inconsistent, it will be necessary either to change (correct) the model and reanalyze the original statistics, or exclude

the forecast from consideration altogether (which may be done, for example, if there is a possibility of an abrupt change in the lead sector, or in case of improper use of, or lack of, statistics). If the heuristic forecasting is at fault, it can be repeated, either with discussion of the results with the original experts, or with the participation of new experts. The questions relating to the combination of forecasts examined below apply not only to heuristic-mathematical forecasts, but also to other variants of combined forecasts (for example, the combination of different mathematical forecasts). And so, let us assume that there are several (specifically two) forecasts, produced by different methods, concerning one and the same quantity for one and the same moment, or moments, of time in the future.

Let us formulate the problem of combining two forecasts as follows.

We have data for forecasting a quantitative characteristic of a given process $y(t)$ by two different methods:

$\hat{y}_{\rm I}(t_{\rm fc})$, $\hat{y}_{\rm II}(t_{\rm fc})$ are point forecasts;

$\hat{\Delta}_{\rm I}(t_{\rm fc})$, $\hat{\Delta}_{\rm II}(t_{\rm fc})$ are interval forecasts for a given level of probability P.

We are required to produce a combined forecast—point $\hat{y}_{\rm c}(t_{\rm fc})$ and interval $\hat{\Delta}_{\rm c}(t_{\rm fc})$ at the required level of probability—based on a combination of the two forecasts.* As follows from the foregoing discussion, the solution of this problem consists of two independent subproblems:

—comparison of the forecasting results for determining their "contradictoriness" or "noncontradictoriness";

—calculation of the value of the combined forecast if the original forecasts are "noncontradictory."

We shall examine each of these subproblems independently.

Comparison of the forecasting results. Let us determine the concepts "contradictoriness" and "noncontradictoriness" of the forecasts introduced earlier.

A comparison of the point and interval forecasts can be made on the basis of the following considerations.

Of course, point forecasts will not actually coincide. In practice there are three instances:

—the confidence intervals of one forecast ($\Delta_{\rm I}$) include the confidence intervals of the other ($\Delta_{\rm II}$), and here the common zone (Δ_0) is equal to the zone defined by the confidence intervals of the "inclusive" forecast ($\Delta_0 = \Delta_{\rm II}$);

*[The Russian к (cf. footnote, p. 107) is apparently being used here with the meaning 'combined,' and so is abbreviated with a 'c'—U.S. Ed.]

—the confidence intervals partially overlap;

—the confidence intervals do not have a common zone ($\Delta_0 = 0$).

The following can be taken as a deciding rule for determining the "contradictoriness" of forecasts. The forecasts are considered to be "noncontradictory":

1) if the point forecasts $\hat{y}_I(t_{fc})$ and $\hat{y}_{II}(t_{fc})$ belong to the common zone Δ_0:

$$\hat{y}_I(t_{fc}),\ \hat{y}_{II}(t_{fc}) \in \Delta_0; \tag{1}$$

2) if the size of the common zone Δ_0 is such that

$$\frac{\Delta_0}{\Delta_{\min(I,\, II)}} \geqslant K. \tag{2}$$

If the error distributions of the forecasts are symmetrical (and, as analysis shows, this happens in many cases), on fulfillment of condition (1) where $K = 0.5$ condition (2) is always fulfilled, i.e., in this case the total zone is not less than half the zone with smaller confidence intervals. A more precise value of K should be determined on the basis of the experience of the joint use of the results of the actual forecasting methods in question. The necessity of using condition (2) is also subject to experimental verification.

It should be noted that the size of Δ_0 depends on the level of probability P, in accordance with which the confidence intervals are constructed and, consequently, the fulfillment of condition (1) also depends on the degree of P. However, P is an input element of the forecasting system in the sense that it is determined outside the given forecasting system by forecast quality (accuracy) requirements.

It can also be appreciated that there is another more strict condition, from the point of view of mathematical statistics, which determines the "contradictoriness" or "noncontradictoriness" of forecasts. This is based on the method of verifying a null hypothesis and is as follows.

Consider the quantity

$$t = \frac{\hat{y}_I(t_{fc}) - \hat{y}_{II}(t_{fc})}{\sqrt{\hat{\sigma}_I^2 + \hat{\sigma}_{II}^2}}, \tag{3}$$

where $\hat{\sigma}_I^2$ and $\hat{\sigma}_{II}^2$ are estimates of the variances of the combined forecasts. It is not difficult to show that in a normal distribution of the forecasts it

is distributed according to Student's law with $k = k_1 + k_2$ degrees of freedom, where k_1 and k_2 are, respectively, degrees of freedom of χ^2 distributions of estimates of variances of forecasts $\hat{y}_{\rm I}(t_{\rm fc})$ and $\hat{y}_{\rm II}(t_{\rm fc})$.

Quantities k_1 and k_2 are determined in each specific case, depending on the method of calculating forecasts $\hat{y}_{\rm I}(t_{\rm fc})$ and $\hat{y}_{\rm II}(t_{\rm fc})$, the form of the forecasting models, and the volume of statistics.

For example, if forecast $\hat{y}_{\rm I}(t_{\rm fc})$ is determined by the mathematical extrapolation method using the model

$$y = \sum_{i=1}^{n} a_i x_i + \eta \tag{4}$$

(one of the x_i is time t), then dispersion of the forecast is estimated by means of the formula

$$\hat{\sigma}_{\rm I}^2 = \frac{1}{N-n} \sum_{j=1}^{N} \left(y_j - \hat{a}^{\rm T} \bar{x}_j\right)^2 \bar{x}_{\rm fc}^{\rm T} (BB^{\rm T})^{-1} \bar{x}_{\rm fc}, \tag{5}$$

where

N = the number of points of observations (statistics) of process y;
n = the number of unknown coefficients a_i of the model;
fc = an index which characterizes the point of forecast:

$$\bar{x}_{\rm fc}^{\rm T} = (x_{1\,{\rm fc}},\ x_{2\,{\rm fc}},\ \ldots,\ x_{n-1,\,{\rm fc}},\ t_{\rm fc});$$

$B = \|x_{ij}\| =$ a matrix of dimension ($n \times N$) of the values of elements of x_{ij} for different observations (thus the element of x_{ij}, which appears at the intersection of the ith line and the jth column, denotes the value of t—which is a component of vector $\bar{x}$ for the jth observation).

In this case the quantity

$$V = \frac{1}{\sigma^2} \sum_{j=1}^{N} \left(y_j - \hat{a}^{\rm T} \bar{x}_j\right)^2,$$

where σ^2 is the variance of interference η, is distributed according to the χ^2 law with $N - n$ degrees of freedom and

$$k_1 = N - n. \tag{6}$$

If forecast $\hat{y}_{II}(t_{fc})$ is determined as the average R of forecasts $\hat{y}_{IIr}$ (t_{fc}), which can be given, for example, by experts, or by means of statistical modeling:

$$\hat{y}_{II}(t_{fc}) = \frac{1}{R}\sum_{r=1}^{R}\hat{y}_{II_r}(t_{fc}), \tag{7}$$

the variance of the forecast is determined as follows:

$$\hat{\sigma}_{II}^2 = \frac{1}{R-1}\sum_{r=1}^{R}\left[\hat{y}_{II}(t_{fc}) - \hat{y}_{II_r}(t_{fc})\right]^2 \tag{8}$$

and

$$k_2 = R - 1. \tag{9}$$

Here the degree of freedom of the Student distribution for the example under consideration will be

$$k = k_1 + k_2 = N + R - n - 1. \tag{10}$$

Determination of the "contradictoriness" or "noncontradictoriness" of the forecasts in the case in question is based on verification of the hypothesis regarding the equality of the centers of distribution of forecasts $\hat{y}_I(t_{fc})$ and $\hat{y}_{II}$ (t_{fc}):

$$M\left[\hat{y}_I(t_{fc})\right] = M\left[\hat{y}_{II}(t_{fc})\right]. \tag{11}$$

For practical purposes the verification of this hypothesis boils down to calculating equation (3) and establishing whether or not the inequality

$$|t| < t_{q,k}, \tag{12}$$

is fulfilled, where $t_{q,k}$ is the tabluated q-percent limit for a Student distribution with k degrees of freedom [5].

If inequality (12) is fulfilled, there is reason to assume that with a probability of $1-q$ the forecasts are "noncontradictory." More precisely, the probability of the fact that the centers of grouping of the forecasts do not coincide equals $\frac{q}{100}$. Otherwise the forecasts can be considered "contradictory" (from the point of view of the statistics on the basis of which they were worked out).

It is not difficult to see that the fulfillment of inequality (12) may depend on the magnitude of q. In other words, one and the same forecast

may prove to be "noncontradictory" at one level of significance of q and "contradictory" at another. If q is increased, the value of $t_{q.k}$ (for one and the same k) will decrease and the forecasts may become "contradictory." However, the reliability of such verification decreases in this case, since events with probabilities of 0.2–0.3, for example, cannot be considered impossible in practice.

If the level of significance decreases, the values of $t_{q.k}$ increase and there is a danger of taking as "noncontradictory" forecasts which do not belong to the same general interval. Usually taken as practically impossible deviations are those whose probability does not exceed 0.05 or 0.01, i.e. q = 5 percent or q = 1 percent are taken as the levels of significance. Of course, it is impossible to give for all cases in life an identical recommendation about which improbable event should be considered practically impossible, since the degree of risk associated with the disregard of unlikely events depends on the importance of the consequences of the occurrence of such events.

In some cases where there are sufficient statistics (when, for example, $k>30$) we can disregard the decrease in accuracy of the estimate by substituting a normal distribution for a Student distribution. In this case, having taken the estimates of variances $\hat{\sigma}_I^2$ and $\hat{\sigma}_{II}^2$ as the actual values of variances σ_I^2 and σ_{II}^2, we find that quantity

$$t = \frac{\hat{y}_I(t_{fc}) - \hat{y}_{II}(t_{fc})}{\sqrt{\sigma_I^2 + \sigma_{II}^2}}$$

is distributed according to the normal law $N(t, 0, 1)$, given the assumption of the "noncontradictoriness" of the forecasts. Here the condition of "noncontradictoriness" will be equivalent to fulfilling the inequality

$$|t| < z_q, \qquad (13)$$

where z_q is the tabulated q-percent limit of deviation for the normal law [5].

Concerning the selection of quantity q, obviously we can cite the same considerations here as for Student's law.

The above methods of estimating "contradictoriness" and "noncontradictoriness" of forecasts are not, of course, exhaustive. More complicated criteria can also be used, including, for example, variance distribution characteristics, as well as certain logical conditions, determinable by the specific nature of the process being forecast.

At the same time, the use of these criteria provides a basis for going on to the next stage—the stage of computing the combined forecast.

Calculation of the value of the combined forecast. We shall assume that we have grounds for supposing that the results of the two methods of forecasting are noncontradictory, i.e., the forecasting methods being combined give an estimate of the future value of the quantity being forecast that is not too far displaced from the original forecasts.

It should be noted that, as a rule, the forecasts being combined are not equally precise (in the sense of the variance of the forecast errors). Nevertheless, combination does make sense, since, as will be shown below, the error (variance) of a combined forecast can be made less than the smallest variance of the individual forecasts to be combined, i.e., in the statistical sense a combined forecast has a greater degree of accuracy than any of the individual forecasts alone.

The physical justification for this assertion consists in the fact that different forecasts can be based on a variety of independent information, various models, conjectures, and assumptions, which complement each other in combination. Given a forecast $\hat{y}_{I}$, produced by means of forecasting system I and $\hat{y}_{II}$, produced by means of forecasting system II, let us see how we can obtain a combined forecast $\hat{y}_{c}$ which is more accurate.

First, we shall formulate the combined forecast in the form

$$\hat{y}_k = w_I \hat{y}_I + w_{II} \hat{y}_{II}, \text{*} \tag{14}$$

where w_I and w_{II} are the weights of forecasts I and II, respectively, related by the condition

$$w_I + w_{II} = 1, \tag{15}$$

which is necessary to satisfy the condition of nondisplacement of the combined forecast.

From an examination of expression (14) it is evident that the problem of obtaining a combined forecast amounts to seeking weights w_I and w_{II} which ensure the minimum error variance of the combined forecast.

*[It will be noted that an ordinary k was printed here as a subscript to the y. Judging, however, by the text immediately preceding, which refers to a *combined* forecast, and judging also by the immediately following usage of symbols, it would appear that this was a misprint for a small Cyrillic K, which would then indicate that it was being used as an abbreviation rather than an arbitrary symbol. The value of this Cyrillic letter in this context is as an abbreviation for *combined*, and so the letter c should probably appear here in the English translation rather than *k*—U.S. Ed.]

In the general case the variance of a combined forecast can be written as follows:

$$\sigma_c^2 = w_I^2\sigma_I^2 + w_{II}^2\sigma_{II}^2 + 2w_I w_{II} r\sigma_I\sigma_{II}, \qquad (16)$$

where

σ_I^2 and σ_{II}^2 = unknown variances of the forecasts;

r = the correlation coefficient of the indicated forecasts.

From the condition of minimum dispersion of σ_c^2—taking into account expression (15)—we obtain an expression for the optimal (in the sense of minimum variance) weight w_I in the form

$$w_I = \frac{\sigma_{II}^2 - r\sigma_I\sigma_{II}}{\sigma_I^2 + \sigma_{II}^2 - 2r\sigma_I\sigma_{II}}, \qquad (17)$$

and weight w_{II} in the form

$$w_{II} = \frac{\sigma_I^2 - r\sigma_I\sigma_{II}}{\sigma_I^2 + \sigma_{II}^2 - 2r\sigma_I\sigma_{II}}. \qquad (18)$$

In this case the expression for the minimum variance of the combined forecast will take the form

$$\sigma_c^2 = \frac{\sigma_I^2\sigma_{II}^2(1 - r^2)}{\sigma_I^2 + \sigma_{II}^2 - 2r\sigma_I\sigma_{II}}. \qquad (19)$$

It is not difficult to show that the variance of the combined forecast is not greater than the variance of the individual forecasts.

Actually, taking into consideration equation (19), we find

$$\sigma_c^2 - \sigma_I^2 = -\frac{\sigma_I^2(\sigma_I - r\sigma_{II})^2}{(\sigma_I - r\sigma_{II})^2 + \sigma_{II}^2(1 - r^2)} < 0, \qquad (20)$$

and by virtue of the symmetry of expression (19)

$$\sigma_c^2 - \sigma_{II}^2 = -\frac{\sigma_{II}^2(\sigma_{II} - r\sigma_I)^2}{(\sigma_I - r\sigma_{II})^2 + \sigma_{II}^2(1 - r^2)} < 0. \qquad (21)$$

We find the range of values of r, for which $\sigma_c^2 < \sigma_I^2$ (where σ_I^2 is the smallest of the forecast variances).

It follows from an analysis of expressions (17), (18), and (20) that to achieve inequality (21) it is essential to achieve the inequality

$$r \neq \frac{\sigma_I}{\sigma_{II}} \text{ (where } \sigma_I < \sigma_{II}). \qquad (22)$$

The value of $r = \frac{\sigma_I}{\sigma_{II}}$ is the boundary value at which

$$\left.\begin{aligned} w_I &= 1; \\ w_{II} &= 0, \end{aligned}\right\}$$

and $\sigma_c^2 = \sigma_I^2$.

Where there is no correlation ($r = 0$) of the individual forecasts to be combined, which is often the case in practice, expressions (17) and (19) are reduced to the form:

$$w_I = \frac{\sigma_{II}^2}{\sigma_I^2 + \sigma_{II}^2}; \tag{23}$$

$$\sigma_c^2 = \frac{\sigma_I^2 \sigma_{II}^2}{\sigma_I^2 + \sigma_{II}^2}. \tag{24}$$

If, moreover, the forecasts are equally precise ($\sigma_I^2 = \sigma_{II}^2 = \sigma^2$):

$$w_I = w_{II} = \frac{1}{2}; \tag{25}$$

$$\sigma_c^2 = \frac{1}{2}\sigma^2, \tag{26}$$

i.e., in this case the combined forecast is found as the arithmetic mean of the forecasts being combined and has a 30-percent gain in accuracy, since $\sigma_c = 0.706\sigma$.*

Thus, if the statistical characteristics of the forecasts (σ_I^2, σ_{II}^2, r) are known, then the optimal (in the sense of minimum variance) forecast can be obtained by means of formula (14), and the weights are determined by formulas (17) and (18).

It should be noted that in actual conditions, as a rule, the values of σ_I^2, σ_{II}^2 and r are unknown, and only their estimates (obtained by one means or another) may be known: $\hat{\sigma}_I^2$, $\hat{\sigma}_{II}^2$, $\hat{r}$. Accordingly, in calculations in expressions (17), (18), and (19) the corresponding estimates will appear and estimates of $\hat{\sigma}_c^2$, $\hat{w}_I$, $\hat{w}_{II}$ will be obtained, which, generally speaking, will differ from the optimal.

*[This is probably intended to be 0.707σ—U.S. Ed.]

Example 40. Let us consider an example of the compilation of a combined forecast of a future value of technical specification A from heuristic (Example 26) and mathematical forecasting data given in table 16.

Table 16.

Characteristics of forecast	Method of forecasting	
	Heuristic (in which the "weights" of the experts are identical)	Mathematical
Point forecast, A	3.3	3.45
Mean square error of forecast	0.20	0.48

First, we shall compare the heuristic and mathematical forecasting data. Then in accordance with expression (3) we shall determine

$$t = \frac{3.45 - 3.3}{\sqrt{0.04 + 0.23}} = 0.29.$$

Taking into consideration the fact that the mathematical forecasting was done by the least squares method for $N = 13$ statistical points on a linear model with $n = 3$ unknown coefficients, and that the number of experts participating in the questioning was $R = 9$, we find by means of formula (10) the number of degrees of freedom for the Student distribution:

$$k = N + R - n - 1 = 13 + 9 - 3 - 1 = 18.$$

According to the table [5] of values of q-percent limits for a Student distribution with 18 degrees of freedom for $q = 5$ percent we find

$$t_{q,k} = t_{5,18} = 2.101.$$

In this case inequality (12) is achieved, since

$$|t| = 0.29 < t_{q,k} = 2.101,$$

and we have grounds for assuming that the heuristic and mathematical forecasts are noncontradictory.

We can now go on to calculate the combined forecast.

Assuming that the forecasts are uncorrelated ($r = 0$), we determine their weight in accordance with formulas (23) and (15):

$$w_h = \frac{0.48^2}{0.2^2 + 0.48^2} = 0.82;$$

$$w_m = 1 - 0.82 = 0.18.$$

The point combined forecast is determined by means of formula (14)

$$A_k = w_h A_h + w_m A_m = 0.82 \cdot 3.3 + 0.18 \cdot 3.45 = 3.33,$$

and the variance in accordance with formula (24)

$$\hat{\sigma}_k^2 = \frac{\hat{\sigma}_h^2 \hat{\sigma}_m^2}{\hat{\sigma}_h^2 + \hat{\sigma}_m^2} = \frac{0.2^2 \cdot 0.48^2}{0.2^2 + 0.48^2} = 0.034,$$

which is less than the smallest of the variances of the individual forecasts, whence $\hat{\sigma}_c$ = 0.184.

Having assumed that the combined forecast has a normal distribution, we find the interval forecast (for a probability level $P = 0.997$).

$$\Delta = \pm 3\hat{\sigma}_k = \pm 0.55.$$

Thus, the definitive combined forecast will take the form: "The future value of technical specification A with a probability of 99.7 percent will be in the range $2.78 \leq A \leq 3.88$."

4. Concluding Remarks

In the preceding section we showed how to combine the results of heuristic and mathematical forecasting. Such a combined forecast is, in a statistical sense, more accurate than individual heuristic and mathematical forecasts. However, this combination represents only one of the possibilities of the use of heuristic elements (specifically, logical analysis) in the research process of forecasting. A logical interpretation of the contradictions of forecasts of interrelated processes may prove extremely useful. Thus, bibliography item [73] cites an example showing that data on the increase of scientific personnel in the U.S. during the period 1940 through 1950 indicated an exponential growth rate in excess of the population growth of that country. Obviously this contradiction can be used as an indication of a future change (in this case a decrease) in the numbers of these personnel (an abrupt change of coefficient in the exponential index), which did in fact occur at the end of the 1960's and the beginning of the 1970's.

This and similar examples are associated with the forecasting and analysis of characteristics of processes developing in parallel. In a good many cases it is useful (if this is theoretically possible at the present level of knowledge) to consider the forecasting of a given process in relation to the forecasting of a number of processes which influence the given process. The so-called scenario method, based on morphological analysis, is used for this purpose. The scenarios describe different variants of development processes formed by a system of interrelated phenomena.

If it is assumed that some event has occurred (a characteristic of some process has assumed a certain value), further investigation should be directed at calculating the influence of this event on all those that follow. If, for example, the armor protection of a tank is the subject of a forecast, obviously a more accurate result will be obtained by forecasting individual processes which determine the armored protection (characteristics of the steel, changes in structural parameters of the tank, the tactics of its use, antitank defense weapons, etc.) with subsequent calculation of the results of these forecasts in a tank design unit than would be obtained by a statistical extrapolation of characteristics of tank armor protection with respect to time.

As mentioned above, it is possible to combine various mathematical methods of forecasting one and the same process. The results of various mathematical methods of forecasting can be compared and used to obtain a combined forecast on the lines discussed in the preceding section.

In addition, the comparison of various mathematical forecasts of the development of one and the same quantity by means of logical analysis may make it possible to forecast the fact of the approach of an abrupt change in the development of a process (a change of direction in technology, of a physical principle, etc.). For example, a comparison of the general trend in the time-change factor of the speed of long distance passenger transportation (figure 24) using the method of mathematical extrapolation, with curves defining the speed of transportation by water and rail, which enter the saturation sector, suggests a fundamentally different transport facility, which was the airplane, and eventually the orbital spacecraft.

Thus, from the foregoing it follows that both a combination of several methods of forecasting one and the same process and a combination of forecasts of different interrelated processes are very useful. At the same time, there is a need for the creative use of existing methods of forecasting and their further development and use in combination with each other.

Chapter 9. Forecasting and Decisionmaking

1. General Observations

We have been considering methods of forecasting used for solving problems in military affairs. However, it should not be forgotten that the main purpose of forecasting is to obtain information needed for decisionmaking, and it is precisely the requirements of decisionmaking which ultimately determine what should be forecast and how.

In the past, when armed conflict was of a limited nature, military commanders as a rule worked out the operations plans themselves and personally directed the troops on the battlefield. With the passage of time and the increase in the scale of armed conflict, the constantly increasing complexity of weapons and military equipment, and the increased dynamicity of combat operations, it became necessary to establish bodies (staffs) for processing situation data, for making the necessary calculations for obtaining data needed for decisionmaking by the commander. On the subject of staff work Marshal of the Soviet Union I. S. Konev expressed the following thoughts: "Without the extensive and skilled work of staffs it would be simply impossible to work out in detail, precisely plan, and efficiently conduct a battle, even with forces of regimental strength, let alone an army or a front operation. That is why each staff officer should constantly develop and improve himself, strive to know at all times everything necessary about the capabilities and locations of his own and the enemy's forces, and to show initiative and efficiency in his work [30]." A similar picture is also observed in the field of developing and producing modern arms and military equipment. There is no need here to dwell on the question of the importance of a correct, scientifically sound decision, since it is obvious that the consequences of an incorrect decision can be extremely serious.

We could quote many examples of the serious consequences of incorrect forecasting. One will suffice. The Command of the German Fascist Army, drunk with the successes of its summer campaign of 1942, was

unable to forecast correctly the development of the situation in the Stalingrad region. The results of this miscalculation are well known: the encirclement and destruction of a German grouping.

Correct decisionmaking is organically linked with scientifically sound forecasting and is a dialectically indivisible process. In the following sections of this chapter we shall dwell on factors which influence the use of forecasts for decisionmaking, as well as some of the special features of this process.

2. Factors Which Determine the Use of a Forecast for Decisionmaking

Up to now the forecast and the forecasting process have been considered mainly from the point of view of the individual, or the group of individuals, involved in the production of forecasts. However, as we have already mentioned, the results of forecasting constitute the input information for the person (or group of people) responsible for making a decision and planning the implementation of measures for the achievement of a specific goal in the future. Forecasting is not an end unto itself. And, if for a number of reasons (about which we will say more below) certain forecasting results cannot be used in decisionmaking, it means that the effort involved in producing them was in vain.

It should be noted that the process of the calculation and adoption of a decision involves people with varying degrees of mathematical and technical training who may not be thoroughly conversant with the forecasting methods used to produce the forecast submitted to them. Moreover, as a rule these people do not have the spare time and are physically incapable of puzzling over the finer points of a particular forecasting method. They will only be able to use forecasting data for decisionmaking if they are convinced of its usefulness and correctness. From this point of view the results of forecasting work should be presented in such a form that the quality of the forecast and its importance for decisionmaking are in no doubt, otherwise even a good forecast may not be put to use.

The **usefulness** of forecasting results may be judged by the person making the decision on the basis of their **value** for the decision in the making and how easily they can be **understood** (comprehended). At the same time, the forecasting results (input data) should be of greater value for decisionmaking and be more understandable than the input data used in producing the forecast itself, otherwise confidence in the forecasting results will suffer.

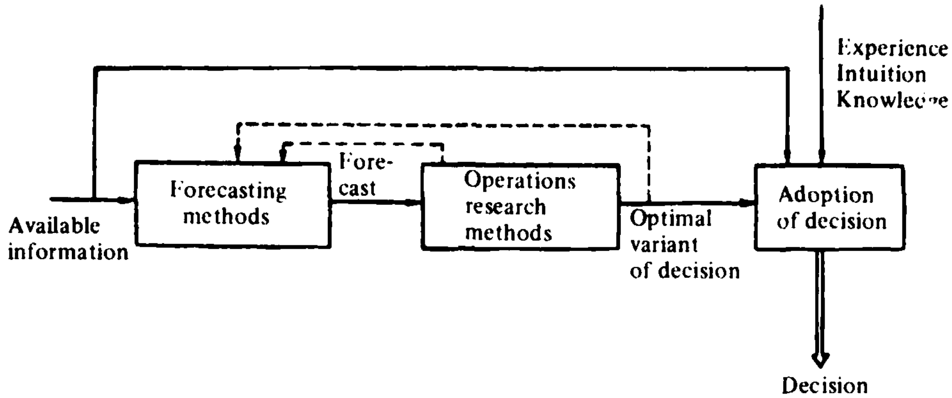


Figure 31. The Process of Decisionmaking.

The decisionmaker can judge the **accuracy** of a forecast on the basis of how much clearer the picture of a future situation is with an analysis of the forecasting results than without it.

Let us take note of some of the factors that influence perception of the usefulness and accuracy of a forecast by the decisionmaker. A necessary condition of the usefulness of a forecast is its direct relationship to the decision being made. Here the decisionmaker should, where this is not obvious, clarify for himself (with the forecaster's assistance) whether or not his decision will influence the process being forecast or whether the forecasting results will be reflected in the future situation, regardless of what decision this person makes. An example of the first case is a forecast of the enemy's behavior as it relates to our actions. An example of the second case is a weather forecast submitted to a commander before a decision is made about the future conduct of combat operations. In the first case the value of the forecasting results will be greatly enhanced in the decisionmaker's eyes if, in addition to the results of forecasting a change in a process as it relates to which version of a decision he adopts, he is also informed of the probable difficulties which may have to be overcome in the implementation of a particular decision.

The usefulness of forecasting results may depend on the degree of preparation of the data and the "language" in which it is presented to the decisionmaker. Just how necessary it is to pay serious attention to the preparation of convincing data for decisionmaking is illustrated by the following historical example.

In her memoirs Laura Fermi describes the preparatory work as a result of which President Roosevelt made the decision to appoint the

Advisory Committee on Uranium [57]. L. Szilard, E. Wigner, and A. Einstein

> tried to estimate how far the Germans had been able to advance in their research since Hahn had succeeded in splitting the uranium atom. Several months had passed since that event, and with the Teutons' efficiency much could have been accomplished in that time. The American government should be informed of these matters with no delay. The three scientists decided that they would prepare a letter to President Roosevelt and send this letter signed by the foremost scientist in America—Einstein. . . . This letter was composed, amended, and discussed by several physicists. . . . Szilard then asked economist Alexander Sachs to deliver this letter to the President. On October 11 [1939] Roosevelt received Sachs, read Einstein's missive, and had a long conversation with Sachs. At once the President appointed an "Advisory Committee on Uranium."*

In order to ensure that forecasting results are clearly understood and their usefulness not open to doubt, it is necessary to stipulate precisely those uncertainties which may accompany the phenomenon being forecast in the future, to characterize their possible level, and to spell out the limitations under which the forecasting was carried out. The usefulness of a forecast becomes very doubtful if it is equivocal (ambiguous). Ambiguity in a forecast may be the natural consequence of the influence of numerous uncertainties attending the process being forecast, if the investigator forecasting this process has not studied it in sufficient depth (or did not have the opportunity to study it). At the same time, this may prove to be a device on the part of the forecaster, who wishes to avoid responsibility for the forecasting results. However, in either case, an ambiguous forecast does not facilitate, but rather complicates, the task of a person making a crucial decision.

Bibliography item [73] contains an example which shows that, despite the fact that the Americans were in possession of deciphered Japanese reports to the forces and diplomatic representatives clearly indicating that the Japanese were planning aggressive action against the Americans, the value of this information was nullified because forecasts based on it and reflected in reports to General Short and Admiral Kimmel at Pearl Harbor bore the stamp of ambiguity. In particular,

> Not one of the reports, with the exception of a message sent on 17 June 1940, contained the word "alert." The reports contained such phrases as "something is being planned," or "in the course of a month it may become clear," or "be ready for surprise actions which may take place in any direction. . . ." For example, a report sent on 17 November 1941, which said "it is impossible to foresee the future actions of the Japanese," contained nothing new in

* [This translation is a slightly free one, but comes very close to the English version and conveys the essence of the original—U.S. Ed.]

addition to what was already known to General Short and Admiral Kimmel. . . .*

It is quite obvious that these and similar forecasts contribute nothing to timely and correct decisionmaking.

Yet another factor which increases the usefulness of a forecast is its quantitative, as opposed to qualitative, character. Let us compare, for example, two forecasts: "it is possible that the enemy will become active on a given sector of the front" and "it is possible that during the next 24 hours the enemy will mount an offensive at point *A* with forces comprising two motorized infantry battalions and one tank battalion." The use of quantitative estimates was one of the main reasons for the success of the "Delphi" method of heuristic forecasting. Let us say a few words now about factors which strengthen the confidence of the decisionmaker in the accuracy of the forecast. The decisionmaker should be convinced of the fact that the forecast submitted to him describes the future situation in the best possible way at the existing level of knowledge and information about the process being forecast.

Thus it can be seen that the question of presentation referred to above is very important in that it facilitates understanding and comprehension of the forecasting results. Another vital factor in this connection is the degree of correspondence between the results of forecasting by different methods, which form the basis of a single, combined forecast, as also is the unanimity of participants in an interrogation of experts (unanimity of opinions of individuals responsible for drawing up an operations plan).

A decisionmaker is favorably impressed by the brevity and precision of the formulations and, as already mentioned, the quantitative nature, of a forecast.

We should also mention the psychological effect of the form of presentation of forecasting results on a person. Here we quote several interesting examples of poor presentation contained in J. P. Martino's book [73].

In presenting forecasting results in the form of a graph (figure 32) the impression is created that extrapolation involved only one observation point, and this immediately puts the accuracy of the quoted forecast in doubt. Obviously the diagram should have included the results of all the observations on the basis of which the given forecast was made.

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* [Again, although essentially the same, the Russian is not identical to the original—U.S. Ed.]

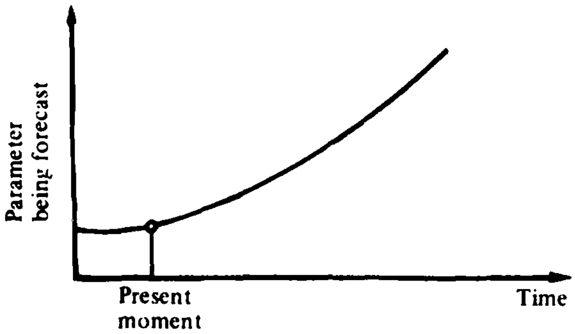

Figure 32.

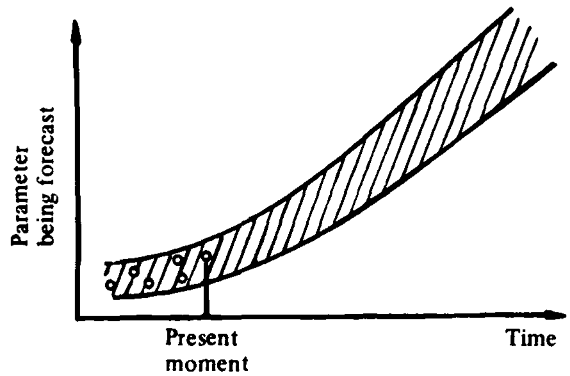

Figure 33.

The form in which the forecasting results are presented (figure 33), notwithstanding the observation results cited, possesses the fault that the shape of the extrapolation curve is not indicated, neither are the values of the upper and lower confidence intervals of the region, in which with a certain degree of probability the appearance of the future value of the parameter being forecast is expected.

Figure 34 depicts the variation curve of a forecast parameter, which reaches saturation at some moment of time in the future, indicating the attainment of a certain limit beyond which further development of this parameter is precluded. This fact should be stipulated precisely and the reasons for it clearly explained; otherwise the decisionmaker might think that "the forecaster simply lost his nerve and would not project continuation of an obvious trend."

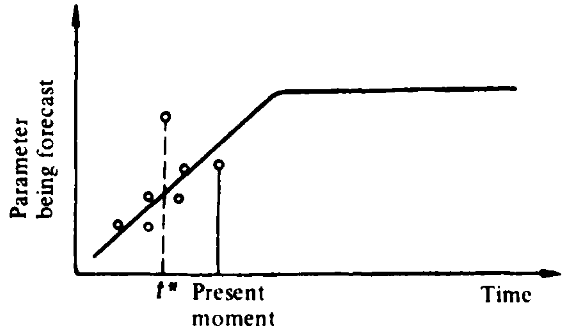

Figure 34. Illustrating the Influence of the Form of Presentation of Forecasting Results on the Decisionmaker.

Another fault is failure to explain the presence of substantial deviations (for example, at moment of time t^*, figure 34) from the total set of observations. The forecaster should stipulate precisely the reasons for such deviations analyzed by him and explain how they were used (or why they were not used) in producing the forecast. Actually, substantial deviations should be given very careful consideration, especially in processing experts' forecasts, when one person, who presents the course of development of the forecast process better than the others, may go beyond the limits of the general aggregate of answers given by the rest of the panel.

In conclusion, it is pointed out that the forecaster should be ready to provide the decisionmaker with the answers to a number of questions concerning the forecast, for example:

What information does the forecast contain that will be useful to the decisionmaker?
What method of forecasting was used?
On the basis of what information was a given forecast produced?
What assumptions were made in producing the forecast?

Although the forecaster will have encountered all these questions in the process of forecasting, he should systematize them, in order to be able to give clear and precise answers.

3. Forecasting and Decisionmaking

In the preceding section we examined a number of factors which positively or negatively influence the use of the forecasts for decisionmaking.

Decisionmaking is the operation of selecting one of several possible courses of action. In practice a particular course of action can be selected only on the basis of a number of indices, which as a rule are in conflict. The main problem in decisionmaking is the search for a compromise between contradictory desires to increase (or decrease) these indices. In the Great Patriotic War for example, the preeminence of Soviet artillery over the enemy artillery was manifested in full measure. This was the consequence of the farsightedness of the political and military leadership of the country, which adopted a number of correct and timely decisions relating to the development of artillery and the training of specialists. Here is what Marshal of the Soviet Union G. K. Zhukov said on this question:

> Long before the outbreak of the Great Patriotic War our Party and its Central Committee, foreseeing the importance and role of artillery on the battlefields, took the appropriate measures for ensuring that the country's Armed Forces were provided with artillery and mortars of the latest design. The entire system of training establishments (artillery schools, the Artillery Academy, refresher and conversion courses) turned out highly qualified officer personnel. Those members of the High Command staff who headed the artillery of the Soviet Army, must be given the credit for the fact that our artillery, in terms of its qualities and the level of training of the officers and all the personnel, was far better than the artillery of the armies of all the capitalist countries. And this was demonstrated throughout the whole of the Great Patriotic War [18].

The decision being adopted should conform to the dynamics of development of the events on which this decision will have an effect; otherwise it will be impossible to implement it. Emphasizing this, Marshal of the Soviet Union G. K. Zhukov writes:

> Unfortunately, there were occasions when the higher authorities issued instructions and orders without considering the time and the condition of the units which had to carry out the order. Such instructions did not keep abreast of events in the ebb and flow of the battles, and when they did reach the troops, they were incompatible with the new situation. As a result it transpired that sometimes the order expressed only a fervent desire, which bore no relationship to the actual capabilities of the troops. This caused the subordinate commanders a great deal of trouble and anxiety! [18].

Obviously, such occurrences can be avoided only if, on careful analysis of the prevailing situation, a decision is made on the basis of an accurate forecast of its development in the future.

Another important problem in decisionmaking is the question of the necessary amount and form of information, including forecast information, since the procurement of information inevitably involves expenditures of time and resources. Moreover, as we have already mentioned, under present-day conditions a decision can be correct only if it is based on scientifically substantiated processing of this information, obtained on

the basis of strict scientific methods of decision preparation. Even if only one important factor is omitted as a consequence of the absence of information or underestimation of its importance, the adopted decision, when put into effect, will not meet the requirements of the future situation. An illustration of this situation can be seen in a case where the psychological factor was not taken into account in the adoption of a decision concerning the foxhole system of defense, reflected in prewar instructions. In this system, it was asserted, the infantry would suffer fewer losses from enemy fire. However, in the words of Marshal of the Soviet Union K. K. Rokossovskiy:

> In the final analysis a man is a human being and, naturally, especially in time of danger, he wants to see his comrade beside him and, of course, his commander . . . and the squad commander undoubtedly needs to see his men: to encourage this one, to praise that one—in a word, to be able to influence the men and keep them in hand. The foxhole system of defense proved unsuitable for war. . . . Everyone came to the conclusion that the foxhole system should be scrapped immediately in favor of trenches [43].

Consequently, a person making a decision should base his thinking on a consideration of the various important aspects of a fact and utilize the required information accordingly.

One of the most important methods of obtaining information for decisionmaking under combat conditions is intelligence. Its exceptional role is emphasized by Marshal of the Soviet Union G. K. Zhukov:

> . . . I would like to refer again to intelligence, that most important factor of armed conflict. It has been shown by the experience of past wars that intelligence information and its proper analysis should serve as the basis for situation assessments, decisionmaking, and operations planning. If intelligence were incapable of providing the correct information, or if errors were made in analyzing it, then even a decision made by all the command-staff authorities would inevitably lead in a false direction. As a result the course of the operation itself would not develop as originally intended! [18].

As in the solution of various forecasting problems, a person making a decision encounters a number of uncertainties. The consequences of the selection of each of the alternative courses of action are not entirely clear, he is not fully confident that each of the courses of action will lead to the planned objective, and, finally, he is not always completely sure that there are not other, better alternatives. All of this underlines the enormous role of experience, intuition, and knowledge of the person responsible for making the decision. The ability to make correct decisions and command troops is compounded of knowledge, experience, and intuition, together with such personal qualities as determination, boldness, and courage. Here, as in forecasting, it is necessary to be able to make a decision and accept responsibility for it and its consequences. Marshal of the Soviet Union I. S. Konev wrote:

The principal combat qualities of a military leader are the ability to command troops and constant readiness to accept responsibility, both for what he has already done and for what he intends to do. A resolve to carry responsibility for all the actions of the troops, for all the consequences of the orders he gives—whatever may threaten and whatever the outcome—that is the first and most important sign of strength of will in a commander. In the course of the war army and front commanders had to accept this kind of responsibility, and at the beginning of the war to accept it under the most difficult conditions. And this was one of the most important factors in their development as military leaders [27].

He emphasized the role of such factors as inspiration in decisionmaking in a combat situation:

. . . Direction of combat operations is primarily a matter of inspiration, and it is precisely this, above all else, that a commander needs before making his most difficult decisions [27].

In concluding this consideration of the question of the importance of constant improvement of the knowledge of all military matters and the inculcation of specific qualities in individuals responsible for decisionmaking, we quote the words of Marshal of the Soviet Union I. S. Konev on the role and the place of regimental and divisional commanders in war:

. . . In war the regimental commander was an expert, who was indispensable in any matter, any department, particularly the department of war. Things will not work out in industry without a master expert in all the elements, and likewise in war, things will not go well without a regimental commander—an expert in all the elements of the organization of combined-arms combat. . . . It was these very regimental commanders who developed into divisional and corps commanders and other prominent military leaders in the course of the war. . . .

I would like to say a few words about the role of the divisional commander. Like the regimental commander, he is the principal organizing figure of combined-arms combat. A divisional commander does not fulfill his purpose if he is incapable of making proper use in combat of all branches of the troops that make up the formation and are under his command. It is important that he be able to correctly understand and assess the general operational situation in which his units are taking part. A divisional commander has on his staff a group of specialists, and if he does not rely on them, if he does not make use of their knowledge, he himself falls short of the demands made of him. Neither does he fulfill his purpose if, as sole commander, he does not rely on his deputy and the head of the divisional political section, and if in combat he is unable to make proper use of the enormous resources of the political workers [27].

During recent times extensive use has been made of operations research methods for decisionmaking. Operations research provides the means of elaborating a quantitative framework for decisionmaking. Fundamental in operations research is the systems approach, the essence of

which is that the activity of any part of the system has some effect on the activity of all the other parts of the system. Quantitative data for decisionmaking are obtained as a result of the solution of four basic problems:

—selection of the criteria for optimization;
—construction of a model of the operation;
—determination of the information to be fed into the model (initial data);
—finding the optimal solution by means of mathematical methods.

Thus, operations research methods provide a person making a decision with data which represent the optimal (from the mathematical point of view) solution of a particular problem, i.e., data obtained in accordance with mathematicized common sense.

Every decision, as the term itself implies, is associated with the selection of a future course of action. Therefore, information used in decisions, whether explicit or implicit, is of a prognostic nature. Where we are concerned with preparing a decision by means of operations research methods, this information is primarily the above-mentioned initial data fed into the model. Such source data may be obtained by one of the forecasting methods set forth above.

A common problem in operations research in military affairs is that of searching, when it is required to maximize the probability of finding the sought item with limited resources. For example, we are required to solve the problem of the optimal number of patrols on a particular line. This problem can be solved given the speed of the patrol, the enemy's rate of movement, the distance at which the patrols can detect the enemy, etc. [61]. Obviously, this problem will be of practical value only if there is accurate input information, some of which (for example, the enemy's rate of movement, the detection range of unfamiliar terrain, etc.) can only be obtained by forecasting.

Target distribution problems can be successfully resolved only if there is accurate forecast information about the probability of the destruction of a particular target by a particular weapon, etc. Accurate forecasting information is also required in the solution of problems relating to the management of reserves.

Thus, scientifically sound information forecasting methods are the means of obtaining valuable practical results from the operations research methods devised to date.

However, it would be wrong to consider a one-sided connection between forecasting methods and operations research methods (figure 31). In a good many cases the results of optimizing a future situation make it possible to introduce correctives into the research process of forecasting by acting as a unique form of feedback in the overall process of decisionmaking. In cases where we can actively influence the process being forecast, this operation should take place simultaneously with the solution of the problem of optimizing the future situation. The optimization data in this case will play the aforementioned role of physical limitations used in logical analysis of forecasting results.

A striking example of the combination of the forecasting process with optimization is the diagrammatic method of planning and control. Such methods make it possible to establish objectively the minimum required time and, where necessary, the required expenditure of material resources for carrying out a particular task, thus creating the conditions for making an objective decision. The diagrammatic method of planning and control can also be used successfully in planning the combat training, combat readiness, and combat operations of troops, and in troop command and control [48]. This method is also widely used in military construction projects and the development of new weapons systems, which necessitate extensive programs of complex composite operations involving whole teams of specialists, dozens of different institutions, and numerous plants. Planning diagrams, their analysis and optimization provide the means of bringing about the necessary coordination of actions in time and finding the most effective ways of organization—in the shortest possible time and with the minimum expenditures of material resources.

As developments and experience show, diagrammatic methods of planning may be used with success in scientific research work, in forecasting the most likely conditions of a combat situation in a war in which new weapons are used, and particularly in the forecasting of probable estimates of the time necessary for the fulfillment of particular tasks, in determining the probable rates of offensive, expenditures of material resources, etc. [48].

Similar in meaning are the so-called normative methods of forecasting, which employ data on set objectives and ways of achieving them [69], [67]. In normative forecasting attempts are made to establish global objectives, to analyze what specific subobjectives these may engender, how these objectives tell on the development of the process being forecast, and what resources are needed to achieve the objectives set. It is pointed out that the process of forecasting without optimization should not be regarded as rivaling the process of forecasting with optimization, but as complementing it. Actually, no one will waste time on research forecasting of the development of some technical trend, for example, if

it is considered that it will not be needed in the future. This is an example of the use of the simplest type of normative forecast. Nor will anyone consider development targets which are known to be unattainable (according to research forecast data).

Thus, as follows from the foregoing, the processes of forecasting and the preparation and adoption of a decision are in dialectical harmony.

The forecasting process should be considered as one of the stages in the overall scheme of decisionmaking. In a number of cases, where we are not able to influence the process being forecast (for example, a weather forecast, at the present level of technology), the forecasting process can be accomplished autonomously (independently of the forecasting of other processes). In other cases (for example, in the forecasting of the development of a particular technical trend) the research process of forecasting should be combined with the optimization of the future situation.

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